Final Report on 2002 Airborne Geophysical Survey at Pueblo of Isleta Bombing Targets, New Mexico

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14. ABSTRACT

This report describes the results of a low altitude helicopter geophysical survey performed by US Army Engineering Support Center, Huntsville (USAESCH) and Oak Ridge National Laboratory (ORNL) over areas contaminated by unexploded ordnance on Pueblo of Isleta Nation lands in April/May, 2002. The purpose of the survey was to evaluate improvements to a multi-sensor magnetometry system for ordnance detection. Surveys were carried out at three areas designated S-01, S-02, and S-07 on the Pueblo of Isleta where the Department of Defense previously had conducted bombing exercises. These areas totaled over 320 hectares. In addition, a 0.03 hectare calibration grid was surveyed. The average rate of coverage for sites S-01, S-02, and S-07 was 103 ac/hr and the average survey speed was 24 m/s.

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List of Acronyms

AGL	Above ground level
AS	Analytic signal
ASCII	American Standard Code for Information Interchange
ADU	Attitude determination unit
BBR	Badlands Bombing Range, South Dakota
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DAS	Data analysis system
DoD	Department of Defense
DQO	Data Quality Objective
ESTCP	Environmental Security Technology Certification Program
FAA	Federal Aviation Administration
GIS	Geographic Information System
GPS, DGPS	(Differential) Global Positioning System
HAZWOPR	Hazardous Waste Operations and Emergency Response
INS	U.S. Immigration and Naturalization Service
MTADS	Multi-Sensor Towed Array Detection System
NAD	North American Datum
ORAGS	Oak Ridge Airborne Geophysical System
ORNL	Oak Ridge National Laboratory
RMS	Root-mean-square
SERDP	Strategic Environmental Research & Development Program
TIF, GeoTIF	(Geographically referenced) Tagged Information File
TF	Total (magnetic) field
USAESCH	U.S. Army Engineering and Support Center, Huntsville
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance

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Abstract

This report describes the results of a low altitude helicopter geophysical survey performed by U.S. Army Engineering Support Center, Huntsville (USAESCH) and Oak Ridge National Laboratory (ORNL) over areas contaminated by unexploded ordnance on Pueblo of Isleta Nation lands in April/May, 2002. The purpose of the survey was to evaluate improvements to a multi-sensor magnetometry system for ordnance detection. Surveys were carried out at three areas designated S-01, S-02, and S-07 on the Pueblo of Isleta where the Department of Defense previously had conducted weapons tests and bombing exercises. These areas totaled over 320 hectares. In addition, a 0.03 hectare calibration grid was surveyed. The average rate of coverage for sites S-01, S-02, and S-07 was 103 ac/hr and the average survey speed was 24 m/s.

Detection declarations were made based on the detection of UXO plus fragments and produced a 78% success rate at S-02 and 86% at S-01. The S-01 results are reduced to 56% when considered against the full list of ground excavations, due to an apparently high detection threshold used in the anomaly selection process. Most misses were Mk-76 practice bombs buried at 0.75 meter or greater depth. Items were frequently missed when the total magnetic field anomaly fell below about 4.6 nT. The average distance between the actual locations of the excavated items and the predicted locations from helicopter anomalies averaged 31cm at S-02 and 103cm at S-01. No miss distance could be calculated for S-07 because excavation positioning data were not available. Noise levels of magnetometers fell within acceptable limits, typically less than 1 nT.

1 Introduction

1.1 Background

Portions of lands belonging to the Pueblo of Isleta Nation have been contaminated with unexploded ordnance (UXO) through Department of Defense (DoD) activities, e.g. during training exercises or during weapons tests. As there was no clear understanding as to the nature and extent of the UXO contamination, a low-altitude airborne geophysical survey was conducted in order to demonstrate its efficacy as an economical rapid reconnaissance tool at UXO sites.

This report describes the results of a low altitude helicopter geophysical survey performed by Oak Ridge National Laboratory (ORNL) and the U.S. Army Engineering Support Center, Huntsville (USAESCH) over UXO-contaminated areas on Pueblo of Isleta tribal lands. The areas, located southwest of Albuquerque, New Mexico, were flown in three survey blocks designated S-01, S-02, and S-07. Supplemental data were also acquired over a temporary calibration site. Surveys were flown so as to completely cover the area of the suspected bombing targets.

The survey was carried out from April 10 to May 6, 2002 in conjunction with a survey of suspected targets on the Pueblo of Laguna (ORNL, 2005). Mobilization of U.S. and Canadian-based crews began on April 10; however, U.S. Immigration and Naturalization Services (INS) grounded the aircraft and air crew at the U.S.-Canada border until April 19 because of insufficient documentation. During this period between the start of mobilization and the arrival of the air crew, each of the survey grids was investigated on the ground, and the Calibration Site was prepared and surveyed using ground-based geophysical instruments. Upon arrival of the Canadian aircraft and crew, equipment installation and calibration flights were conducted. Total magnetic field data were collected between April 21 and April 29 (Isleta sites flown April 27 through 29). Between April 30 and May 4, surveys using an experimental electromagnetic survey system and a vertical magnetic gradient system were conducted over portions of several target areas for the Environmental Security Technology Certification Program (ESTCP) in cooperation with the Pueblo of Isleta Nation. This report addresses only the performance of the total magnetic field system. Treatment and discussion of the vertical magnetic gradient system and the electromagnetic system are covered in separate reports.

1.2 Objectives of the Demonstration

The objectives of the demonstration survey are:

- To provide a means of determining the improvement resulting from recent modification in the Oak Ridge Airborne Geophysical System (ORAGS) total field magnetometry system;
- To assess the capabilities of the system at a site representing conditions and ordnance types typically found on former DoD ranges;
- To detect and map UXO and UXO-related items for subsequent clearance actions.

1.3 Regulatory Drivers

UXO clearance is generally conducted under CERCLA authority. Irrespective of lack of specific regulatory drivers, many DoD sites and installations are pursuing innovative technologies to address a variety of issues associated with ordnance and ordnance-related artifacts (e.g. buried waste sites or ordnance caches) that resulted from weapons testing and/or training activities. These issues include footprint reduction and site characterization, areas of particular focus for the application of technologies in advance of future regulatory drivers and mandates.

1.4 Stakeholder/End-User Issues

The Pueblo of Isleta sites are Formerly Used Defense Sites and as such it is important that concentrations of ordnance and locations of possibly live ordnance be mapped so that actions can be taken toward removal of UXO or safeguards can be established where there is the possibility that live ordnance is still in place. It is also important that a permanent record be maintained to document all measurements that are made to support clearance activities. Advanced technology is expected to contribute to the performance of these activities in terms of efficiency as well as cost.

2 Technology Description

2.1 Technology Development and Application

The total field system is a fourth-generation airborne magnetometer array (Figures 2.1 and 2.2) that we have designated as the ORAGS-Arrowhead system. Changes from the previous ORNL airborne magnetometer array, the ORAGS-Hammerhead, include a new boom architecture designed to position sensors at low-noise locations, and a new aircraft orientation (attitude determination) system. The new attitude determination unit (ADU) is based on four Global Positioning System (GPS) antennas rather than fluxgate magnetometer measurement as in previous generations. For the ORAGS-Arrowhead system, four magnetometers at 1.7-meter spacing are located in a forward V-shaped boom assembly, and two magnetometers with equivalent spacing are located in each of the lateral booms. Although the spacing is similar to that of the predecessor ORAGS-Hammerhead system, moving two magnetometers that were previously the innermost rear boom magnetometers on the Hammerhead system to the forward boom assembly of the Arrowhead improved noise conditions over those of the Hammerhead system.

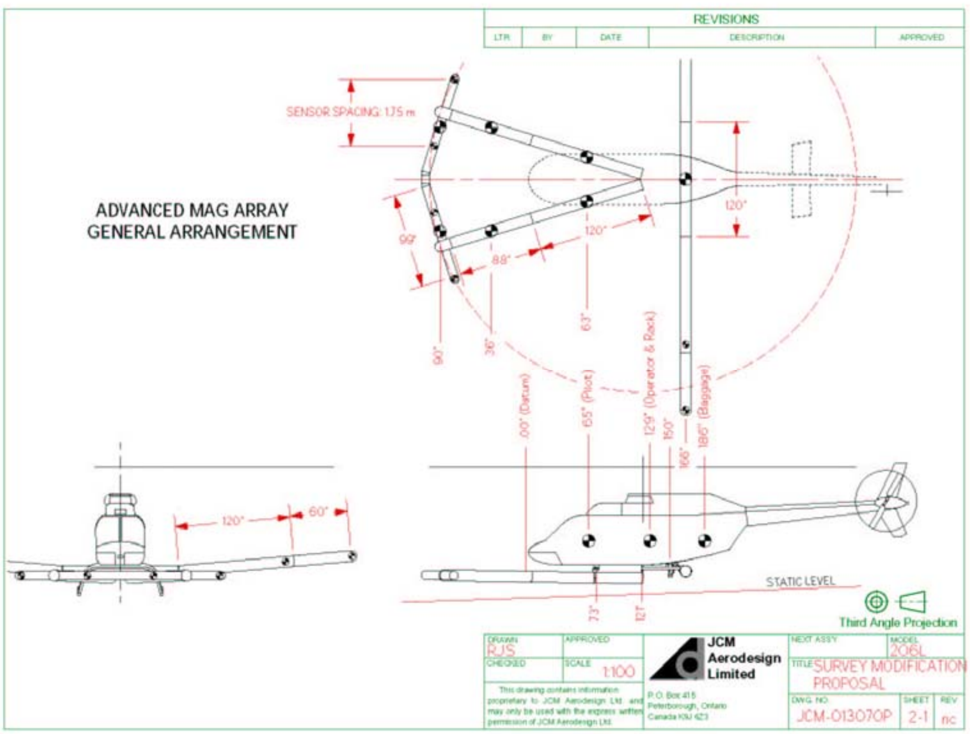

Figure 2.1 Schematic for the ORAGS-Arrowhead airborne total field magnetometer system that has been constructed to evaluate the improvements over previous generations of total field systems.


Figure 2.2 ORAGS-Arrowhead helicopter total field magnetometry system at site S-01.

2.2 Previous Testing of the Technology

ORNL has previously tested two generations of boom-mounted airborne magnetometer systems for UXO detection and mapping. The first system tested was the HM-3 system, depicted in Figure 2.3, developed by Aerodat, Ltd., under the direction of J.S. Holladay and T. J. Gamey. The 1999 airborne magnetometer tests at BBR deployed this system, operated by High Sense Geophysics, and modified to meet ORNL requirements (Gamey et al., 2000).

The Vanguard Geophysics VMA system was a 5-sensor array that was developed by Gamey and Holladay after the financial collapse of Aerodat Ltd. In September 2000, ORNL deployed a more advanced helicopter system at BBR, the ORAGS-Hammerhead system, based on the VMA design, in cooperation with Dr. Holladay (now at Geosensors Inc., a teaming partner with ORNL) and Mr. Gamey (now at ORNL). While somewhat similar in appearance to the HM-3 system, this system, illustrated in Figure 2.4, is significantly improved in terms of the number of magnetometers, magnetometer spacing, system positioning, navigation, and data acquisition parameters (Doll et al., 2001; Gamey et al., 2001). Additionally, a dihedral in the boom tubes improved system safety by raising the boom tips.

Figure 2.3 The HM-3 helicopter magnetometry system used by ORNL in 1999 for surveys at Badlands Bombing Range.

Figure 2.4 ORAGS-Hammerhead airborne magnetometer system used at Badlands Bombing Range in FY2000.

2.3 Factors Affecting Cost and Performance

The cost of an airborne survey depends on several factors, including:

- Helicopter service costs, which depend on the cost of ferrying the aircraft to the site and fuel costs, among other factors.
- The total size of the blocks to be surveyed
- The length of flight lines
- The extent of topographic irregularities or vegetation that can influence flight variations and performance
- Ordnance objectives which dictate survey altitude and number of flight lines
- The temperature and season, which control the number of hours that can be flown each day
- The location of the site, which can influence the cost of logistics
- The number of sensors and their spacing; systems with too few sensors may require more flying, particularly if they require interleaving of flight lines
- Survey objectives and density of coverage, specifically high density for individual ordnance detection versus transects for target/impact area delineation and footprint reduction

2.4 Advantages and Limitations of the Technology

Airborne surveys for UXO are capable of providing data for characterizing potential UXO contamination at considerably lower cost than ground-based systems. Current indications are that the survey cost may approach $70.00 per acre under optimal conditions. Furthermore, the data may be acquired and processed in a shorter period of time, thereby reducing the time required for reviewing large areas. Airborne systems are particularly effective at sites having low-growth vegetation and minimal topographic relief. They can also be used where heavy brush or mud makes it difficult to conduct ground-based surveys.

Experience with airborne surveys to date indicates that with existing hardware, a 2nT threshold at a nominal 1 meter above ground level and with low background noise represents the smallest targets that may be detected (see Figure 4.1 in BBR Draft Final Report, ORNL, 2004). This represents targets that are larger those detectable by ground surveys (e.g. towed array surveys using MTADS), which can operate with sensors at less than 0.5m above ground level (AGL). Ferrous items with responses less than 2nT have been documented as having been detected by the ORAGS-Arrowhead system when operating in a background environment of magnetically clean sands (Zapata Engineering, 2004), but this cannot be considered typical.

Both airborne and ground magnetometer systems are susceptible to interference from magnetic rocks and magnetic soils. Rugged topography or tall vegetation limits the utility of helicopter systems, necessitating survey heights too high to resolve individual UXO items.

3 Demonstration Design

3.1 Performance Objectives

Shown in Table 3.1 is a listing of the various performance objectives for this survey.

Table 3.1 Performance Objectives of Arrowhead Airborne Magnetic System

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)	Actual Performance Objective Met?
Qualitative	Total Field (TF) system aerodynamically stable	Pilot report	Yes
Quantitative	TF system has lower noise than predecessors	Comparison of data sets at test site and elsewhere	Helicopter noise in sensors 3&6 reduced by half from previous Hammerhead configuration.
Qualitative/Quantitative	New attitude measurement system provides improved sensor positioning	Comparison of ground follow-up results for target reacquisition radius and comparison of processed results over small known targets	Yes, however difficulties with ADU caused much data to have only marginally improved accuracy.
Qualitative/Quantitative	Improved aircraft compensation over previous systems	Comparison of Figure of Merit (FOM) and compensated profiles with those from Hammerhead system data	FOM = 2.6nT (exceeds previous Hammerhead FOM 3.8 nT)
Quantitative	Probability of detection	>90%	No, 78% S-02
Quantitative	False alarm rate	6%	No, 22% S-02
Quantitative	Location accuracy	<60 cm	31cm at S-02 103cm at S-01
Quantitative	Survey rate	>40 ac/hr	Yes, 103 ac/hour
Quantitative	Percent site coverage	100%	Yes, 100%

3.2 Selecting Test Sites

The airborne survey sites were chosen to enable, where possible, direct comparison of results from the new generation airborne systems with results of ground-based geophysical systems for UXO detection and mapping. Airborne data were acquired at three sites at Pueblo of Isleta. The three survey sites for this demonstration project are three bombing targets on Pueblo of Isleta, identified as Kirtland PBR S-01, Kirtland PBR S-02, and Kirtland PBR S-07. All sites were remote, but accessible by both road and air, and were found to contain significant M38 ordnance debris at the surface.

3.3 Test Site History/Characteristics

The sites selected within the Pueblos of Isleta are Formerly Used Defense Sites (FUDS) located west of Albuquerque in New Mexico. Totaling more than half a million acres, large portions of this typically western desert environment are flat and devoted to ranching. The remaining portions of land are gently rolling to nearly vertical in appearance that have been formed by the extensive erosion of the soft fine-grained underlying sediments, creating canyons, washes, and gullies.

The Pueblo is situated on the eastern edge of the New Mexico portion of the Colorado Plateau, east of the Albuquerque-Belen Basin. Separating the geologic provinces is a series of north-south trending high-angle faults stepping downward from the plateau into the basin. The geology of the area is dominated by both consolidated and unconsolidated units and includes sandstone, mudstone, claystone, and shale. Igneous basalt formations cap the mesas in the area. Typical elevations at the sites are 1500-1800 meters above sea level.

With regard to historical ordnance, numerous sites exist across the entire area that were utilized for aerial bombardment activity, including the three suspected target areas identified for this demonstration. From both visual inspection and previous NRL MTADS surveys at sites in the nearby Pueblo of Laguna, the principal ordnance type present at these sites is the M38 practice bomb. Evidence of these ordnance items is present on the surface at all sites under consideration for this demonstration, with several hundred M38s excavated during the Pueblo of Laguna MTADS demonstration (McDonald and Nelson, 1999).

3.4 Present Operations

Site S-01 at Pueblo of Isleta was surveyed in February-March, 2003 by NRL using airborne and ground MTADS (Nelson et al., 2004) under the guidance of the ESTCP Program Office. No remediation work had been done at the site prior to the MTADS survey.

3.5 Pre-Demonstration Testing and Analysis

Shakedown testing of the assembled airborne system and associated components was conducted in Toronto, Ontario, Canada during December 10-21, 2001. These tests were used to determine whether the completed system and its components were performing as designed.

The airborne magnetic system was flight tested by an aeronautical engineer and determined to be completely flightworthy. The testing validated both the aerodynamic stability and performance of the system. Magnetic noise levels for the system were measured both on the ground and during flight. Total magnetic field data were collected at low altitude over known targets in a seeded test area.

One of the main design changes made in moving from the ORAGS-Hammerhead design to the ORAGS-Arrowhead design was to shift the positions of sensors 3 and 6—the innermost magnetometers on the aft booms of the Hammerhead system, located 2.6 m from the helicopter centerline. On the Arrowhead system, sensors 3 and 6 were re-positioned to the outer parts of the foreboom. This effectively cut in half the noise levels of sensors 3 and 6 without compromising the efficiency of the aerodynamics or the quality of the data from the other sensors.

In summary, all system components in both airborne systems performed as anticipated. The noise levels at the aft inboard magnetometer positions 4.3 meters from the centerline of the helicopter is somewhat higher than the noise levels of the other magnetometers, but is reduced over inboard magnetometers from the ORAGS-Hammerhead system, which were located only 2.6 m from the helicopter centerline. Flight performance and maneuverability were excellent with no ballast required.

3.6 Testing and Evaluation Plan

3.6.1 Demonstration Set-Up and Start-Up

Mobilization involved packing and transporting all system components by trailer to Albuquerque and installing them on a Bell 206L Long Ranger helicopter. Calibration and compensation flights were conducted and results evaluated. The eight cesium magnetometers, ADU, GPS systems, fluxgate magnetometers, data recording console, and laser altimeter were tested to ensure proper operation and performance. The Mission Plan was read and signed by all project participants to assure safe operation of all systems.

3.6.2 Period of Operation

Mobilization of the geophysical crew from Oak Ridge, Tennessee and the flight crew from Toronto, Canada began on April 10, 2002. This required two days travel to Albuquerque for the geophysical equipment trailer. A delay at the Canada-U.S. border postponed the air crew's

arrival until April 18. Installation began on the afternoon of April 18. Calibration site set-up, as well as pre-seed and post-seed ground-based surveys, and site visits to sites at the Pueblos of Laguna and Isleta took place during the mobilization period. Airborne systems demonstration and testing, including tests of two other ORNL airborne systems, continued at the Pueblo of Laguna through May 04. Areas S-01, S-02, and S-07 were surveyed during the period from April 27 through 29. De-installation began in the afternoon of May 4, and the geophysical and air crews departed for Oak Ridge and Toronto, respectively.

3.6.3 Area Characterized

A total of three sites were surveyed. All three surveys encompassing bombing or artillery targets. The areas surveyed at these sites are: S-01, 160 ha (395 acres); S-02, 80 ha (200 acres); and S-07, 80 ha (200 acres). The site of the calibration grid had an area of only 0.03 ha (0.07ac). The total area surveyed by the total field system was 320 ha (795 ac). At the three sites, 100 percent coverage of the target area was attained using 12-m flight line spacing.

3.6.4 Residuals Handling

This section does not apply to this project and report.

3.6.5 Operating Parameters for the Technology

The ORAGS Arrowhead system is designed for daylight operations only. Lines were flown in a generally east-west or north-south pattern depending on local logistics and weather conditions with a nominal 12m flight line spacing for the high density survey coverage. Binary data from the eight magnetometers were recorded on the console at a rate of 1200 samples per second. Typical survey speed for the system was between 80-100 km/hr. Survey height was 1-3 m above ground level. In areas where background magnetic susceptibility and variation is small, vegetation height low, and topographic change gradual, the system can be expected to detect anomalies as small as 2 nT. These thresholds can be expected to increase as any of the aforementioned variables increase.

3.6.6 Experimental Design

The tests conducted with the ORAGS-Arrowhead total magnetic field system are summarized in Table 3.2.

Table 3.2 Field Tests with Arrowhead Total magnetic field System

Test ID	Description	Parameters	Sites
Standard configuration	Test overall system performance (aerodynamics, noise, compensation, positioning, orientation, detection)	Alt = 2m at three Pueblo of Isleta sites	Full survey coverage of three Pueblo of Isleta sites: S-01, S-02, and S-07.

Data quality objectives (DQOs) to be used for this technology demonstration focused on prior-generation airborne results as the baseline performance condition, as well as previous MTADS demonstration data. Analysis of HM-3 data by the Institute for Defense Analyses (Andrews et al., 2001) of the same ORNL data sets indicated 78% to 83% ordnance and 17% to 24% false positives. A subsequent analysis by Scott Holladay of Geosensors confirmed these figures. Holladay's calculations yielded 83% ordnance, 17% false positives, and 0% false negatives (ORNL, 2002). Subsequent ORAGS-Hammerhead airborne surveys at BBR, Shumaker Naval Ammunition Depot and Rocket Test Range, Nomans Land Island, and New Boston Air Force Station yielded results consistent with the previous surveys at BBR. One difference is that positional accuracy of the data has improved from approximately 2m in Hammerhead tests to about 1m with the Arrowhead system. We attribute this to the fact that by moving sensors 3 and 6 to the forward boom, they were closer to the GPS sensor than in the Hammerhead assembly, and less susceptible to mispositioning caused by helicopter yaw.

Given the various considerations associated with both the interpretation of airborne geophysical survey data and the calculations of the various performance parameters, DQOs for the demonstration of the fourth-generation total field system approached or met the current performance parameters. ORNL expected the ORAGS-Arrowhead total field system to provide detection in the vicinity of 90% ordnance with 5% to 7% false positives. All surveys conducted with the Arrowhead total field system were performed as full-density surveys with line spacing established to account for sensor positions such that no gaps or voids exist in any data set, except where planned. Positioning for the anomalies detected, being about 100 cm, fell somewhat short of the performance metric of 60 cm, primarily due to the inconsistency of the orientation system. Area S-02 showed unusually high positional accuracy (average 31cm), which may be attributable to a period of consistent performance in the orientation sensor.

Data processing procedures

The 1200 Hz raw data were desampled in the signal processing stage to a 60 Hz working data set sample rate. All other raw data were recorded at a 60 Hz sample rate. Data were converted to an ASCII format and imported into a Geosoft format database for processing. With the exception of

the differential GPS post-processing, all data processing was conducted using the Geosoft software suite and proprietary ORNL algorithms and filters. The quality control, positioning, and magnetic data processing procedures (steps a-i) are described below.

Quality Control
All data were examined in the field to ensure sufficiently high quality for final processing. The adequacy of the compensation data, heading corrections, time lags, orientation calibration, overall performance and noise levels, and data format compatibility were all confirmed during data processing. During survey operations, flight lines were plotted to verify full coverage of the area. Missing lines or areas where data were not captured were reacquired. Data were also examined for high noise levels, data drop outs, significant diurnal activity, or other unacceptable conditions. Lines flown, but deemed to be unacceptable for quality reasons, were re-flown.

Positioning
During flight, the pilot was guided by an on-board navigation system that used real-time satellite-based DGPS positions. This provided sufficient accuracy for data collection (approximately 1m), but was inadequate for final data positioning. To increase the accuracy of the final data positioning, a base station GPS was established at Albuquerque International Sunport at location (NAD83 35° 02’ 11.51050” N 106° 37’ 17.19129” W NAVD88 1605.50m). Raw data in the aircraft and on the ground were collected. Differential corrections were post-processed to provide increased accuracy in the final data positioning. The final latitude and longitude data were projected onto an orthogonal grid using the North American Datum 1983 (NAD 83) UTM Zone 13N. Vertical positioning was monitored by laser altimeter with an accuracy of 2cm. No filtering was required of these data, although occasional drop-outs were removed.

Magnetic data processing procedure
The magnetic data were subjected to several stages of geophysical processing. These stages included correction for time lags, removal of sensor dropouts, compensation for dynamic helicopter effects, removal of diurnal variation, correction for sensor heading error, array balancing, and removal of helicopter rotor noise. The calculation of the magnetic analytic signal was derived from the corrected residual magnetic total field data.

(a) Time Lag Correction
There is a lag between the time the sensor makes a measurement and when it is time stamped and recorded. This applies to both the magnetometer and the GPS. Accurate positioning requires a correction for this lag. Time lags between the 8 Cs-vapor magnetometers, fluxgate magnetometer, and GPS signals were measured with proprietary ORAGS firmware. This utility sends a single pulse that is visible in the data streams of all three instruments. This lag was corrected in all data streams before processing.

(b) Sensor Dropouts
Cesium vapor magnetometers have a preferred orientation to the Earth’s magnetic field. As a

result of the motion of the aircraft, the sensor dead zones can occasionally align with the Earth's field. In this event, the readings drop out, usually from an average of 53,000 nT to 0 nT. This usually only occurs during turn-around between lines, and rarely during actual data acquisition. All dropouts were removed manually before processing.

(c) Aircraft Compensation
The presence of the helicopter in close proximity to the magnetic sensors results in considerable deviation in the readings, and generally requires some form of compensation. The orientation of the aircraft with respect to the sensors and the motion of the aircraft through the earth's magnetic field are also contributing factors. A special calibration flight is performed to record the information necessary to remove these effects. The maneuver consisted of a square or rectangular-shaped flight path at high altitude to gain information in each of the cardinal directions. During this procedure, the pitch, roll and yaw of the aircraft were varied. This provided a complete picture of the effects of the aircraft at all headings in all orientations. The entire maneuver was conducted twice for comparison. The information was used to calculate coefficients for a 19-term polynomial for each sensor. The fluxgate data were used as the baseline reference channel for orientation. The polynomial is applied post flight to the raw data, and the results are generally referred to as the compensated data. These data are used in the development of the analytic signal maps presented in this report.

(d) Magnetic Diurnal Variations
The earth's magnetic field changes constantly over the course of the day. This means that magnetic measurements include a randomly drifting background level. A base station sensor was established near the GPS base station monument at Albuquerque International Sunport to monitor and record this variation every five seconds. The recorded data are normally subtracted directly from the airborne data. The time stamps on the airborne and ground units were synchronized to GPS time. The diurnal activity recorded at the base station was extremely quiet. In general, the low frequency diurnal variations were less than 5nT per survey line. Processing included defaulting repeated values and linearly interpolating between the remaining points.

(e) Heading Corrections
Cesium vapor magnetometers are susceptible to heading errors. The result is that one sensor will give different readings when rotated about a stationary point. This error is usually less than 0.2 nT. Heading corrections were applied to adjust readings for this effect.

(f) Array Balancing
These magnetic sensors also provide a lower degree of absolute accuracy than relative accuracy. Different sensors in identical situations will measure the same relative change of 1 nT, but they may differ in their actual measured value, such as whether the change was from 50,000 to 50,001 nT or from 50,100 to 50,101 nT. After individual sensors were heading-corrected to a uniform background reading, the background level of each sensor was corrected or balanced to match the others across the entire airborne array.

(g) Regional Removal
Deep-seated, large scale background geology and some cultural features which contribute to the local regional magnetic field were removed using a combination of filtering and splining techniques. The output is a residual magnetic total field. This process also removed all diurnal, heading and balancing effects.

(h) Rotor Noise
The aircraft rotor spins at a constant rate of approximately 400 rpm. This introduces noise to the magnetic readings at a frequency of approximately 6.6 Hz. Harmonics at multiples of this base are also observable, but are much smaller. This frequency is usually higher than the spatial frequency created by near surface metallic objects. This effect has been removed with a low-pass frequency filter.

(i) Analytic Signal
The data resulting from this survey are presented in the form of analytic signal (the square root of the sum of the squares of the three orthogonal magnetic gradients is the total gradient or analytic signal). It represents the maximum rate of change of the magnetic field in any direction (i.e. a measure of how much the measurements would change by moving a small amount in any direction such as left-right, forward-backward, or up-down). This parameter was calculated from the gridded residual total magnetic field data.

There are some advantages to using the analytic signal. For small objects, it is somewhat more straightforward to interpret visually than total field data. Total field measurements typically display a dipolar response signature to small, compact sources, having both a positive and negative deviation from the background. The actual source location is a point between the two peaks, as determined by the magnetic latitude of the site and the properties of the source itself. Analytic signal is more symmetric about the target, is always a positive value and has less dependence on magnetic latitude. Analytic signal maps present anomalies as low intensity to high intensity shapes.

3.6.7 Sampling Plan

This section does not apply to this report.

3.6.8 Demobilization

De-installation was carried out on May 04. Booms were dismounted from the helicopter frame and the magnetometers and GPS instrumentation were disconnected and packed in shipping containers. The containers were placed in a trailer for transport to ORNL. The helicopter crew demobilized and departed for Ontario on May 05, 2002.

4 Performance Assessment

4.1 Performance Criteria

Demonstration effectiveness is determined directly from comparisons of the processed/analyzed results from the demonstration surveys and the ground follow-up, as well as from comparisons to results of previous airborne and ground-based surveys. These comparisons include both the quantitative and qualitative items described in this section. Demonstration success is determined as the successful acquisition of airborne geophysical data (without any aviation incident or airborne system failure) and meeting the baseline requirements for system performance as established previously in this document (Section 3.1). Methods utilized by ORNL on both current and past airborne acquisitions to ensure airborne survey success include daily QA/QC checks on all system parameters in the acquired data sets, a series of compensation flights at the beginning of each survey, continual inspection of all system hardware and software ensuring optimal performance during the data acquisition phase, and review of data upon completion of each processing phase.

Several factors associated with data acquisition cannot be strictly controlled, such as aircraft altitude and attitude. Altitude can be recorded and will enter into the data analysis and comparisons with previous results. The aircraft attitude measuring system provides a documented database that cannot be directly compared with previous surveys when this system was not available. The consistent and scientific evaluation of performance is accomplished by using identical or parallel (where parameters are dataset dependent) processing methods with identical software to produce a final map, and following consistent procedures in interpretation when comparing new and existing datasets from the test sites.

Data processing involves several steps, including GPS post-processing, compensation, spike removal, removal of magnetic diurnal variations, time lag correction, heading correction, filtering, gradient calculations, and gridding. Each step is performed in the same manner on data acquired with sequential generations of system at the same sites, to provide a basis for comparing the performance of the systems. The processing procedures have been selected and developed from experience with similar data over a span of more than five years for optimal sensitivity to UXO.

Data quality objectives, as described in Section 3.6.6 (Experimental Design), were used for this demonstration. Surveys over the previously described test areas were conducted as described in Section 3.6. Data collection occurred at flight altitudes over the various test areas and configurations as described in Section 3.6.6. Data confirmation was in accordance with the processes previously described in this section.

Table 4.1 identifies the expected performance criteria for this demonstration, complete with expected/desired values (quantitative) and/or definitions and descriptions (qualitative). This table also identifies expected performance for each of the technologies presented.

Table 4.1 Performance Criteria

Performance Criteria	Expected Performance Metric (Pre-demo)	Performance Confirmation Method	Actual Performance (Post-demo)
Primary Criteria (Performance Objectives) – Quantitative			
System Performance (total field system)	Ordnance detection – greater than 90%	Comparison of airborne data to excavations	78% at S-02
System Performance (total field system)	False positives – less than or equal to 6%	Comparison of airborne data to excavations	22% at S-02
System Performance (total field system)	Data acquisition rate – greater than or equal to 40 acres per hour	Calculated from survey area and flight hours	103 ac/hour, including turnaround time
System Performance (total field system)	Detection threshold (sensitivity)	Calculation of minimum reliable threshold.	~5 nT for reliable detection
System Performance (total field system)	Anomaly positional accuracy	Comparison of airborne pick locations to excavation locations	31cm at S-02 103cm at S-01
Factors Affecting Technology	Helicopter geophysical noise	Comparison to expected noise levels based on prior geophysical measurements around the helicopter	Rotor noise in sensors 3&6 reduced by half
Factors Affecting Technology	Helicopter geophysical noise	Comparison of sensor compensation measurements against prior compensation values	FOM for sensors 3&6 reduced from 8.1 to 2.9nT.
Primary Criteria (Performance Objectives) – Qualitative			
Process Waste	None	N/A	No process waste.

Secondary Criteria (Performance Objectives) – Quantitative			
Hazardous Materials	None expected, other than spotting charges in M38 practice ordnance	Observations and documentation during excavations	All UXO-related materials excavated were labeled UXO-fragments
Secondary Criteria (Performance Objectives) – Qualitative			
Reliability	No system or component failures	Observations and documentation	No components failed during the total field surveys
Ease of Use	Pilot "comfort" when flying with the system installed	Observations and documentation	Pilot states that he feels at ease flying the system under normal wind conditions
Ease of Use	No ballast required	Observations and documentation	Engineer declared the system balanced without need for ballast
Safety	Conformance with all FAA requirements and requirements as documented in the Mission Plan	Observations and documentation	System met all FAA flightworthiness requirements
Versatility	Cultural feature detection and mapping	Comparison of anomaly count, strength, and position to previously collected MTADS data at PBR N-9 and N-10 regarding barbwire fence crossing the middle of the targets	Fence clearly discernable from ordnance targets.
Maintenance	System mount points, hardware, and component inspection	Observations and documentation	Minimal wear and tear.

4.2 Performance Confirmation Methods

Accurate estimation of two of the system performance criteria, i.e. ordnance detection and false positives, are dependent largely on the method of post-survey excavation used. Two sets of dig lists were derived from the airborne data for each of sites S-01, S-02 and S-07. The first was an automated picking algorithm on the analytic signal and a multi-variate statistical routine to classify the anomalies (see Appendix A for details). The second method involved manual selection and segmentation of targets from the total field data, which were then inverted for location, moment and azimuth using the MTADS-DAS code, and then manually classified for UXO-likeness. The total number of anomaly picks from each area were:

- S-01 stats 9965
- S-01 DAS 1023
- S-02 stats 1487
- S-02 DAS 383
- S-07 stats 9668
- S-07 DAS 929

Full dig lists are provided in digital Appendix G. The number of anomalies in the DAS list is lower than the stats lists due to the manual nature of the selection process, but this also increases the quality of those picks since only textbook anomalies are examined. This means, however, that true UXO may be missed in the process. Only full excavation of the area would produce a value for this False Negative metric.

From these lists, a subset of targets was selected for excavation for performance evaluation. The process used at each site was slightly different. At S-01 the original pick lists included NRL ground and airborne MTADS picks as well as ORNL picks from a subsequent 2003 survey at the same site. A second round of investigation was undertaken using a wider search radius at a number of target locations which had originally reported no potential target source. Excavation results were combined and used to analyze the 2002 survey results. Sites S-02 and S-07 were much simpler and included 49 excavations at S-02 and 50 excavations at S-07. Down sampling of anomalies at these sites was conducted at random with representation across the entire range of UXO-likelihood. No final excavation locations were recorded for S-07. Excavation results are provided in Appendix E. Analysis of results is provided below.

4.3 Data Analysis, Interpretation, and Evaluation

The ORAGS-Arrowhead magnetometer system does not distinguish among the numerous features mapped between UXO and ferrous scrap without interpretation. The total field and analytic signal maps provided in this report depict bombing targets (areas of high ordnance density), infrastructure (fences or larger items or areas of ferrous debris associated with human activity), and potential UXO items (discrete sources). Those responses, interpreted as potential UXO, will likely also include smaller pieces of ferrous debris. Additional analysis and interpretation of the survey results are included in this final project report.

4.3.1 Calibration Site

The Pueblo of Isleta helicopter survey was carried out in the same mobilization as the Pueblo of Laguna helicopter survey, therefore a single grid, set up on Pueblo of Laguna lands, was established for calibration and daily QC. A test grid or calibration site was established at Pueblo of Laguna to verify the system response to expected UXO items under local geologic conditions. A 100m x 25m area was established on a topographically flat region near the N-10 impact area. The location of the grid was chosen based on suitability of the topography and absence of significant vegetation and metallic debris. The dimensions of the grid were chosen to represent a double swath width of the ORAGS helicopter array. Iron stakes were place at the southwest and northeast corners of the grid, and plastic highway placards were positioned for the pilot's visual reference.

Prior to seeding any target items (other than the corner stakes), the area was surveyed with a Geometrics G858 magnetic gradiometer and real-time DGPS navigation system. The lower sensor was positioned approximately 0.45m above the ground, with the upper sensor 0.60m above the lower. Positions provided by the navigation system were adjusted for the 1.35m separation between the GPS antenna and the magnetometers before gridding the magnetic data. The total magnetic field data were processed to remove diurnal magnetic responses.

The results showed low levels of ferrous debris over the grid. Every attempt was made to place targets at a sufficient distance from the clutter to create a distinct anomaly. Six locations were seeded with inert ordnance items obtained from a local stockpile at S-12. Four locations were individual M-38 practice bombs (ferrous metal casings only) at varying compass orientations. Location five included one M-38 practice bomb casing with scattered debris. Location six included scattered debris only. The area was then resurveyed with the same Geometrics instrument as was used in the pre-seed survey.

Results of the pre- and post-seed surveys are shown in Figures 4.1 and 4.2. The large unidentified anomaly in the pre-seed survey data represents a buried source of unknown origin. The list of seeded items (including iron stakes) is presented in Table 4.2. Figure 4.3 shows the total magnetic field anomaly map from an airborne pass at a height of 2 m AGL.

We note that in Figure 4.2, the actual location of the calibration items is consistently offset to the north and west of the analytic signal peak. The cause of the consistent offset is unclear, and may be a result of differences in the two different GPS systems used—the first, a leased Trimble ground system with real-time satellite differential correction used for the ground magnetometer survey and during emplacement of the items, and the second, a NovAtel airborne system with post-processed differential. This consistent offset does not appear in the actual field excavation data. Excavation locations were presumably surveyed with a third system and is consistent with the higher quality airborne data. See for example Figure 4.15, which shows area S-01 excavation locations as well as analytic signal peaks.

Table 4.2 Items emplaced at the Laguna Calibration Site including the eight inert ordnance casings (or pieces of ordnance) and two iron stakes.

Easting	Northing	ID	Descript	Angle	Weight (lb)	Length (in)	Diam (in)	Notes
315963.2	3895364.6	NE	corner	*	*	*	*	
315975.9	3895343.2	NW	corner	*	*	*	*	
315890.5	3895292.6	SW	corner	*	*	*	*	
315877.0	3895314.1	SE	corner	*	*	*	*	
315884.8	3895312.7	T-1	M-38	150	6.00	32	7.5	
315908.3	3895312.8	T-2	M-38 w tail fin	0	7.50	43	7.5	
315916.7	3895331.0	T-3	M-38 w tail fin	50	10.00	33	7.5	
315934.5	3895327.7	T-4	M-38 w tail fin	100	9.00	35	7.5	
315952.7	3895352.2	T-5	M-38 no tail fin	170	3.50	31	7.5	M38 badly decomposed
315954.5	3895353.0	T-5a	tail fin, fin assembly	*	3.00	17	10.0	72” from M38
315953.6	3895354.0	T-5b	fin assembly	*	1.00	10	5.0	69” from M38
315952.4	3895354.0	T-5c	2 tin cans, 7 disks	*	2.00	24	24.0	69” from M38, scattered on 24” circle
315951.2	3895353.5	T-5d	fin assembly, metal sheet	*	1.00	12	12.0	79” from M38, scattered on 12” square
315951.2	3895351.7	T-5e	2 fin assemblies	*	1.50	15	4.0	72” from M38
315953.6	3895349.8	T-5f	tail fin	*	2.00	8	8.0	102” from M38
315964.3	3895345.8	T-6	tail, 3nose, flange, 3det	*	14.00	60	60.0	scattered over 60” circle, wt is total

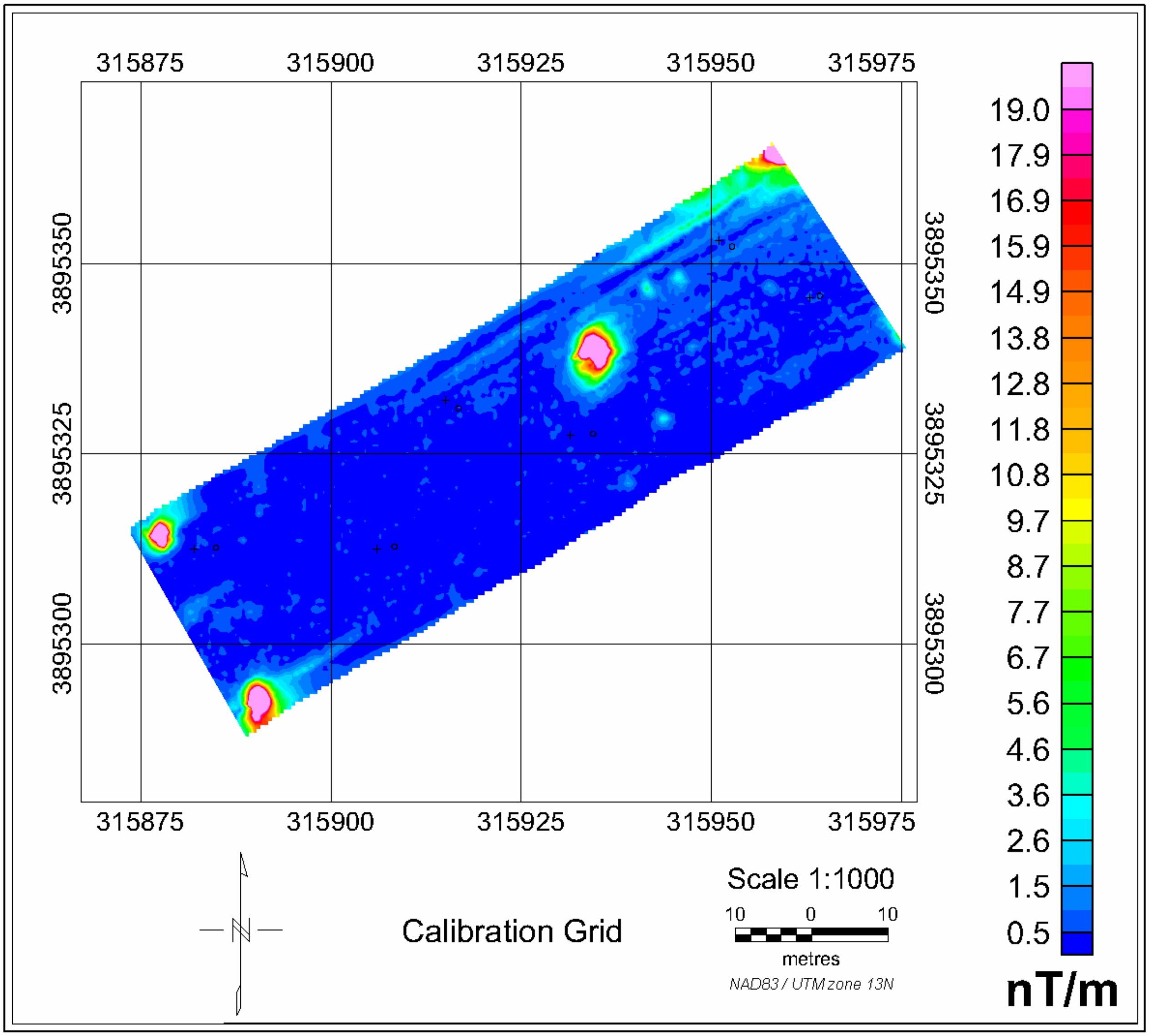

Figure 4.1 Pre-seed analytic signal at nominal height of 2m above calibration grid. Circles indicate airborne analytic signal peak values of test items emplaced after the pre-seed survey; '+' symbols indicate location of test items.

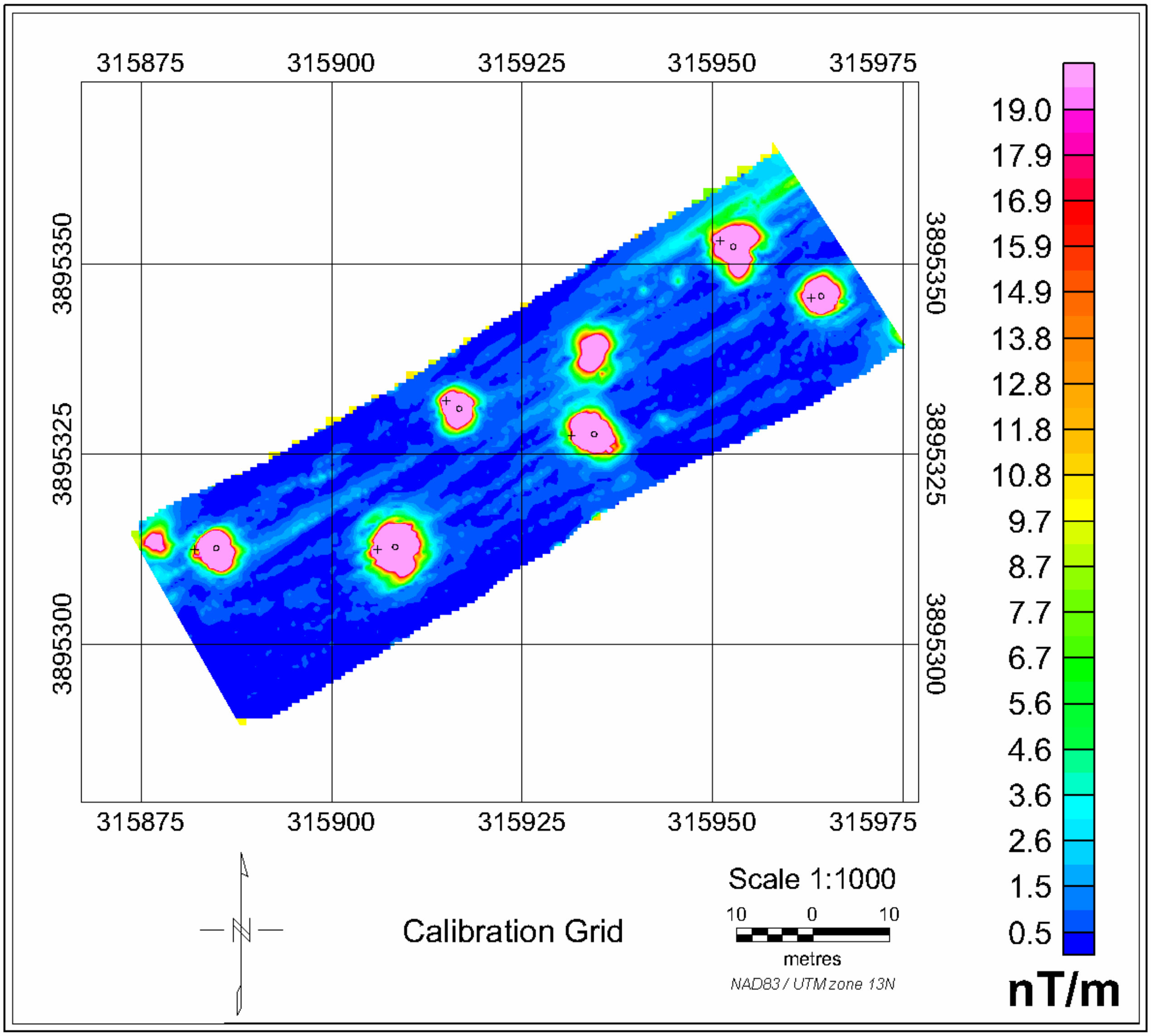

Figure 4.2 Post-seed ground survey, analytic signal. Circles indicate airborne analytic signal peak values of seeded test items; '+' symbols indicate location of test items.

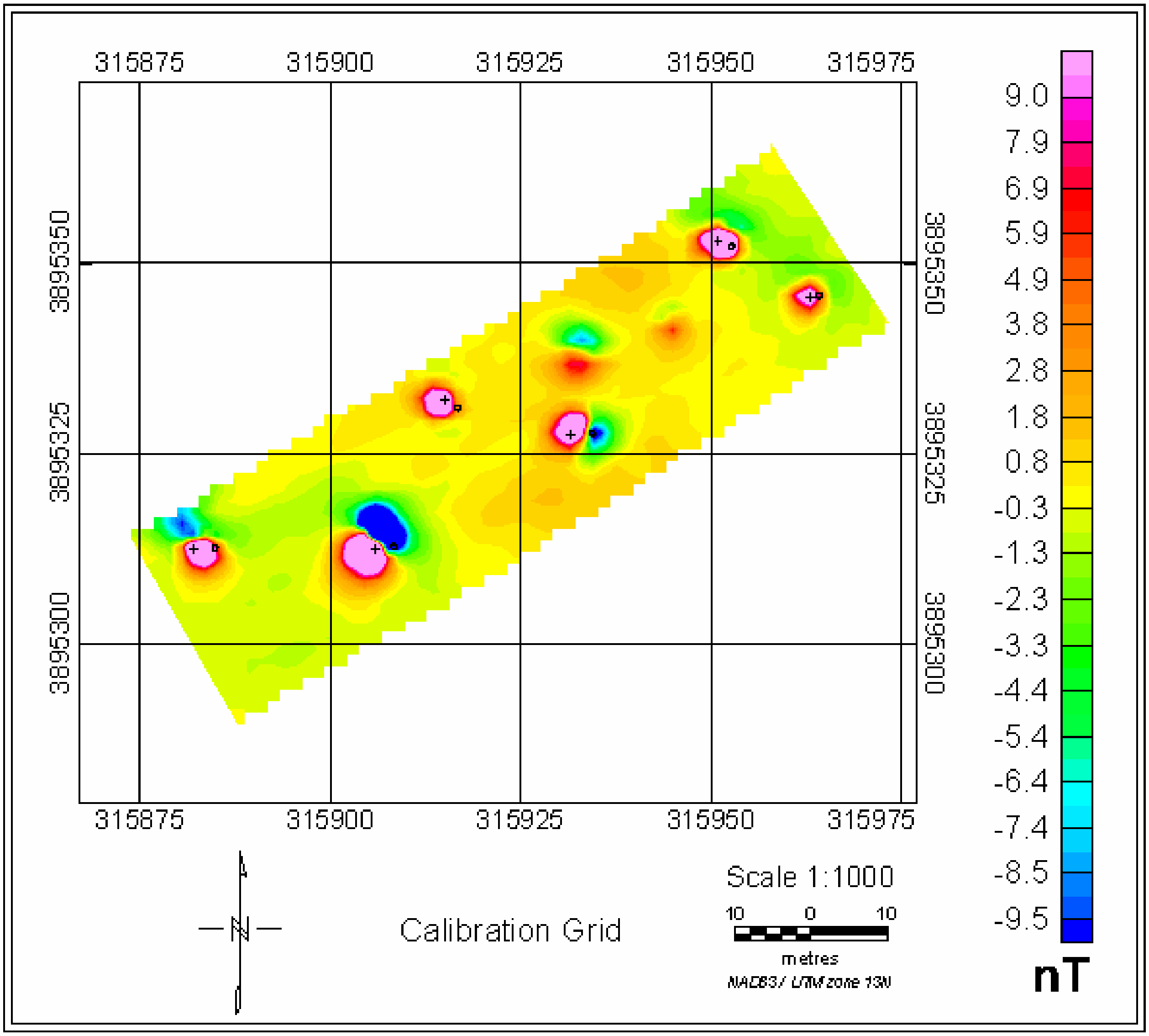

Figure 4.3 Total magnetic field at nominal height of 2m above calibration grid. Circles indicate airborne analytic signal peak values of seeded test items; '+' symbols indicate location of test items.

4.3.2 Site S-01

Site S-01 is a 1.3 km x 1.2 km rectangular area comprising about 160 ha (395 ac) centered over a bombing target. Most of the area is topographically flat with low vegetation, and thus well-suited for low-flying helicopter surveys (Figure 4.4). Lines were flown in an east-west direction, and completely covered the central portion of the target with a 12m flight line separation. Surface fragments indicated that the most likely type of ordnance to be encountered were M-38 practice bombs, although larger bombs were also evident (Figure 4.5). A semicircular anomaly in the western portion of the surveyed area is a berm that marked the bombing target. In the east, a fence runs roughly north-south. Figures 4.6 and 4.7 show anomaly maps of the total magnetic field and analytic signal for a nominal 2 m survey height. The average survey speed in S-01 was 22.5 m/s, and the average coverage rate was 97 ac/hr.

Figure 4.4 View of site S-01, Pueblo of Isleta, New Mexico.

Figure 4.5 Partially buried 500 pound bomb at site S-01. Hand held GPS for scale.

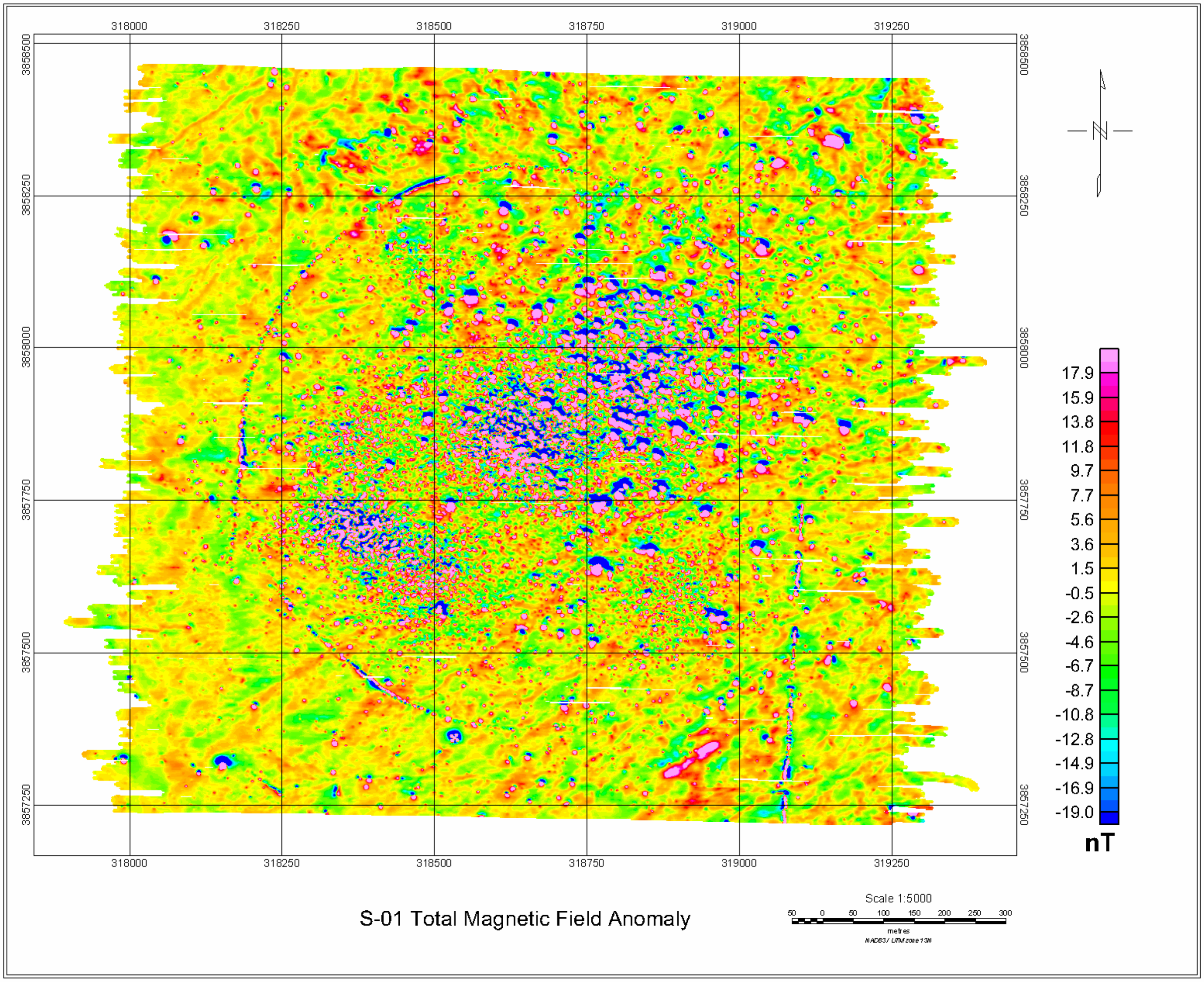

Figure 4.6 Total magnetic field residual anomaly map, site S-01 for a nominal 2m survey height.

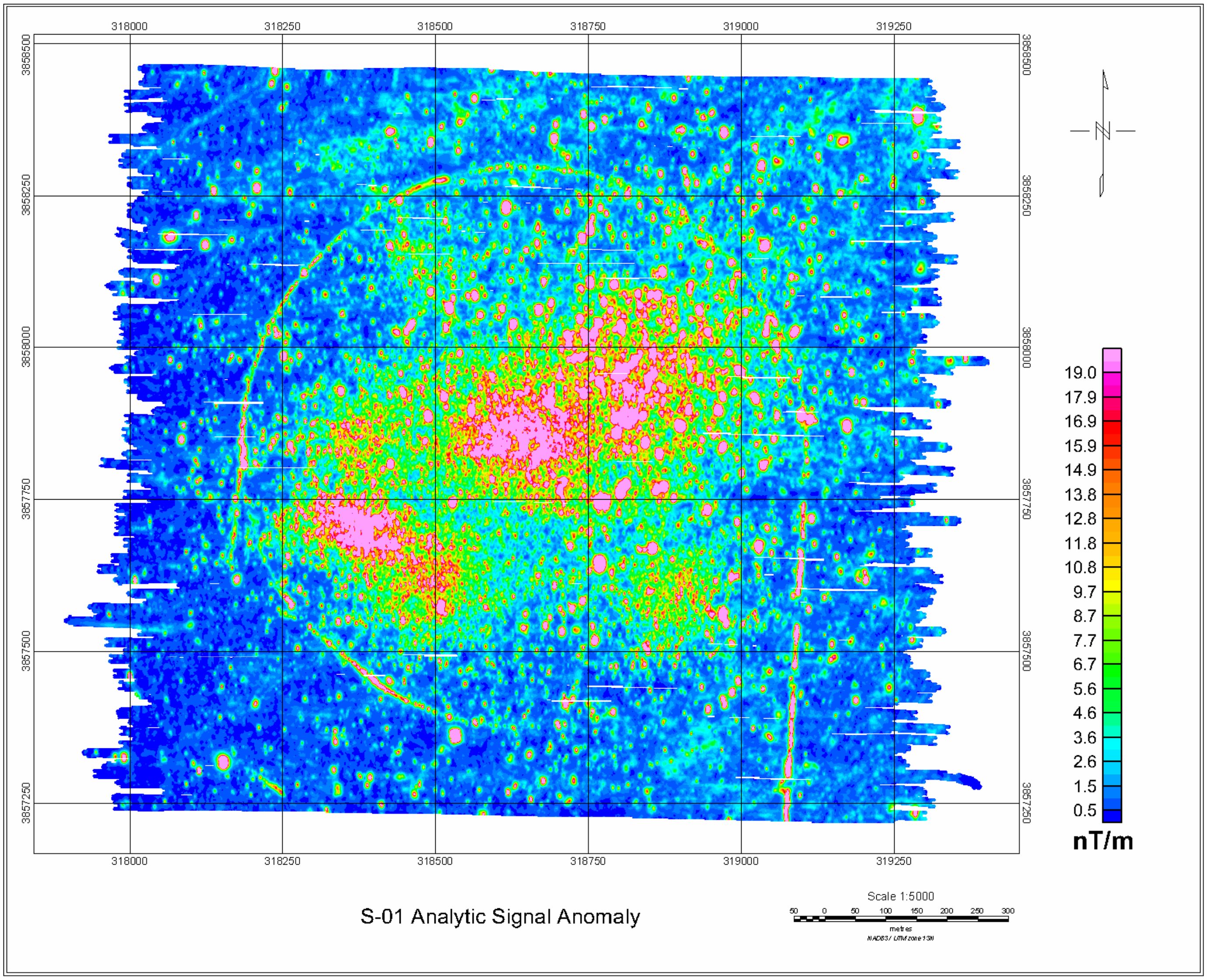

Figure 4.7 Analytic signal anomaly map, site S-01, for a nominal 2m survey height.

4.3.3 Site S-02

Site S-02, comprises a 0.8 km x 1 km (80 ha, 200 ac) rectangle centered over a bombing target. Lines were flown in a roughly north-south direction, and covered the target completely. Total magnetic field and analytic signal anomaly maps are shown in Figures 4.8 and 4.9, respectively, for a nominal survey height of 2m. The average survey speed in S-02 was 24.5 m/s, and the average coverage rate was 107 ac/hr.

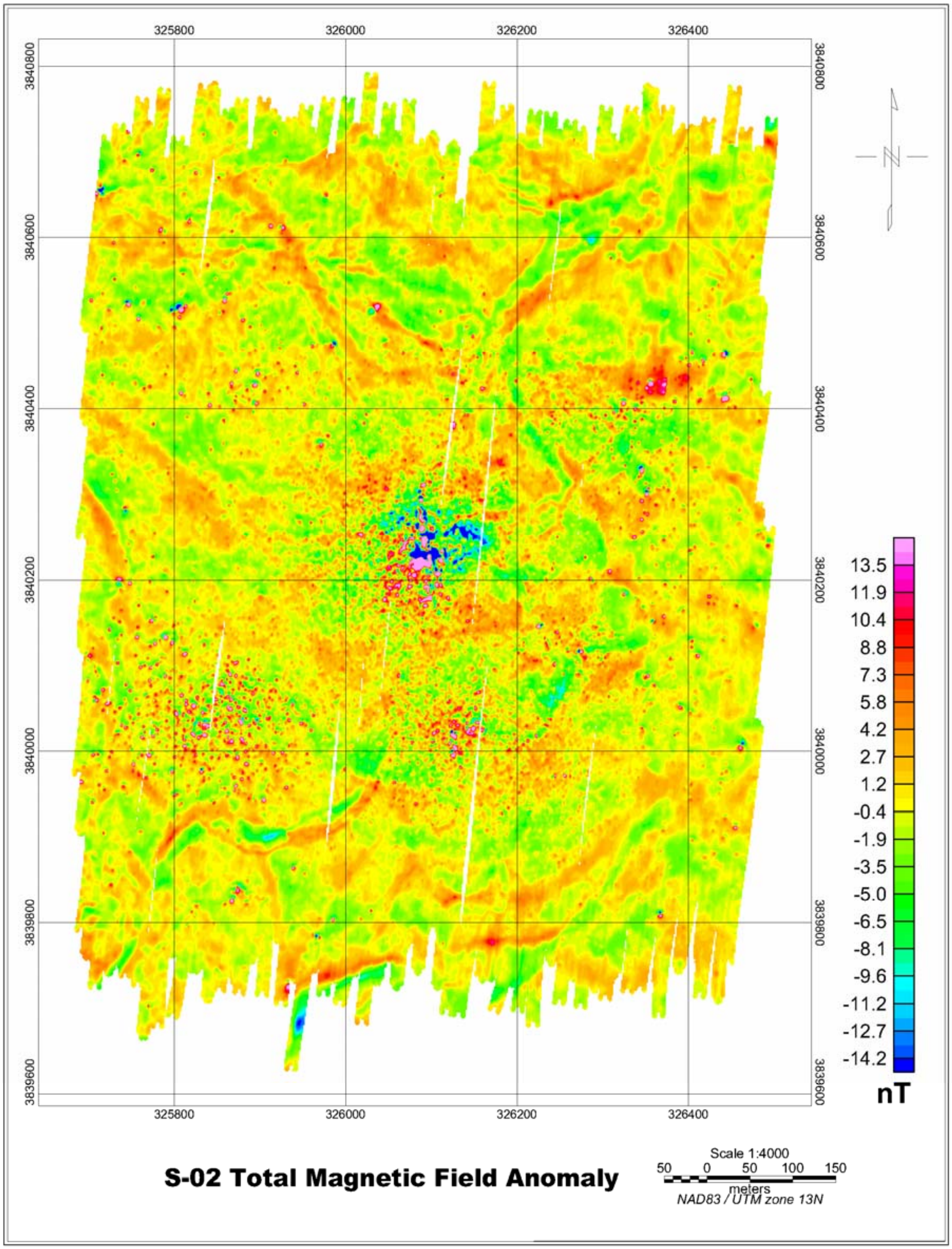

Figure 4.8 Total magnetic field residual anomaly map, site S-02, for a nominal 2m survey height.

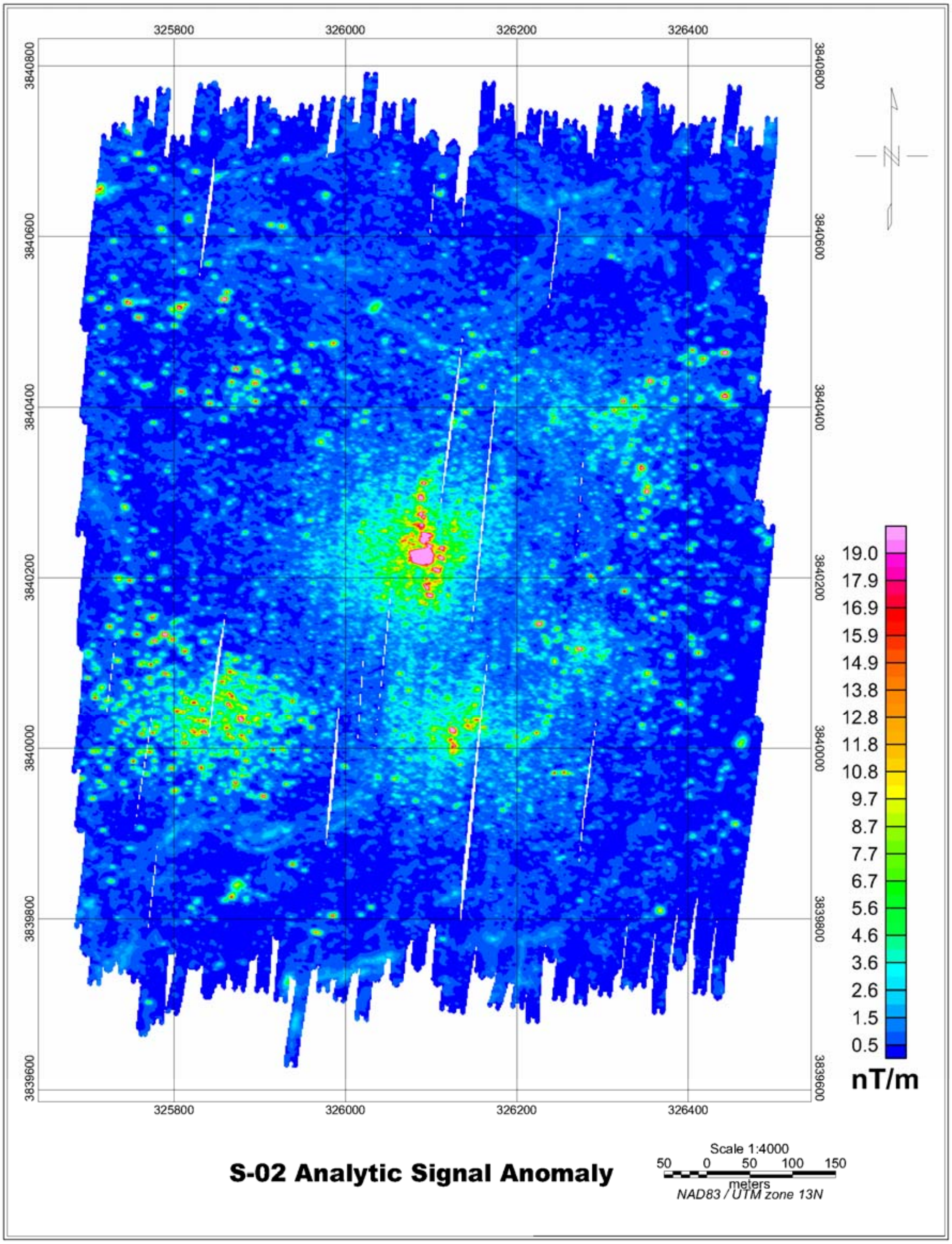

Figure 4.9 Analytic signal anomaly map, site S-02, for a nominal 2m survey height.

4.3.4 Site S-07

Site S-07 is defined by a roughly 1 km x 0.8 km (80 ha, 200 ac) rectangle centered over a bombing target. Lines were flown east-west, and covered the central portion of the target completely, using 12m flight line spacing. Total magnetic field and analytic signal maps are shown in Figures 4.10 and 4.11, respectively, for a nominal survey height of 2 m. The average survey speed in S-07 was 26.5 m/s, and the average coverage rate was 114 ac/hr.

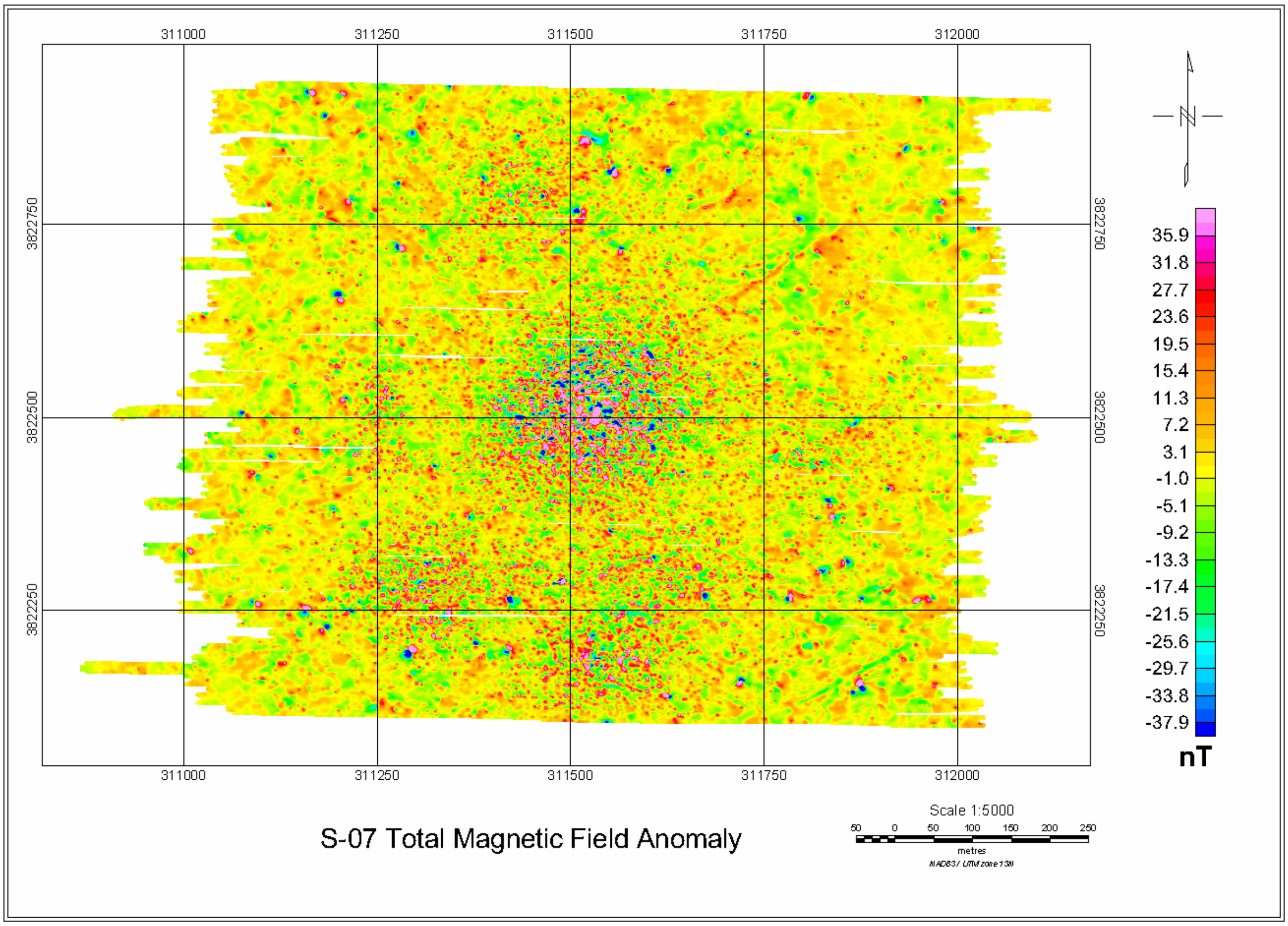

Figure 4.10 Total field anomaly map, site S-07, for nominal 2 m survey height.

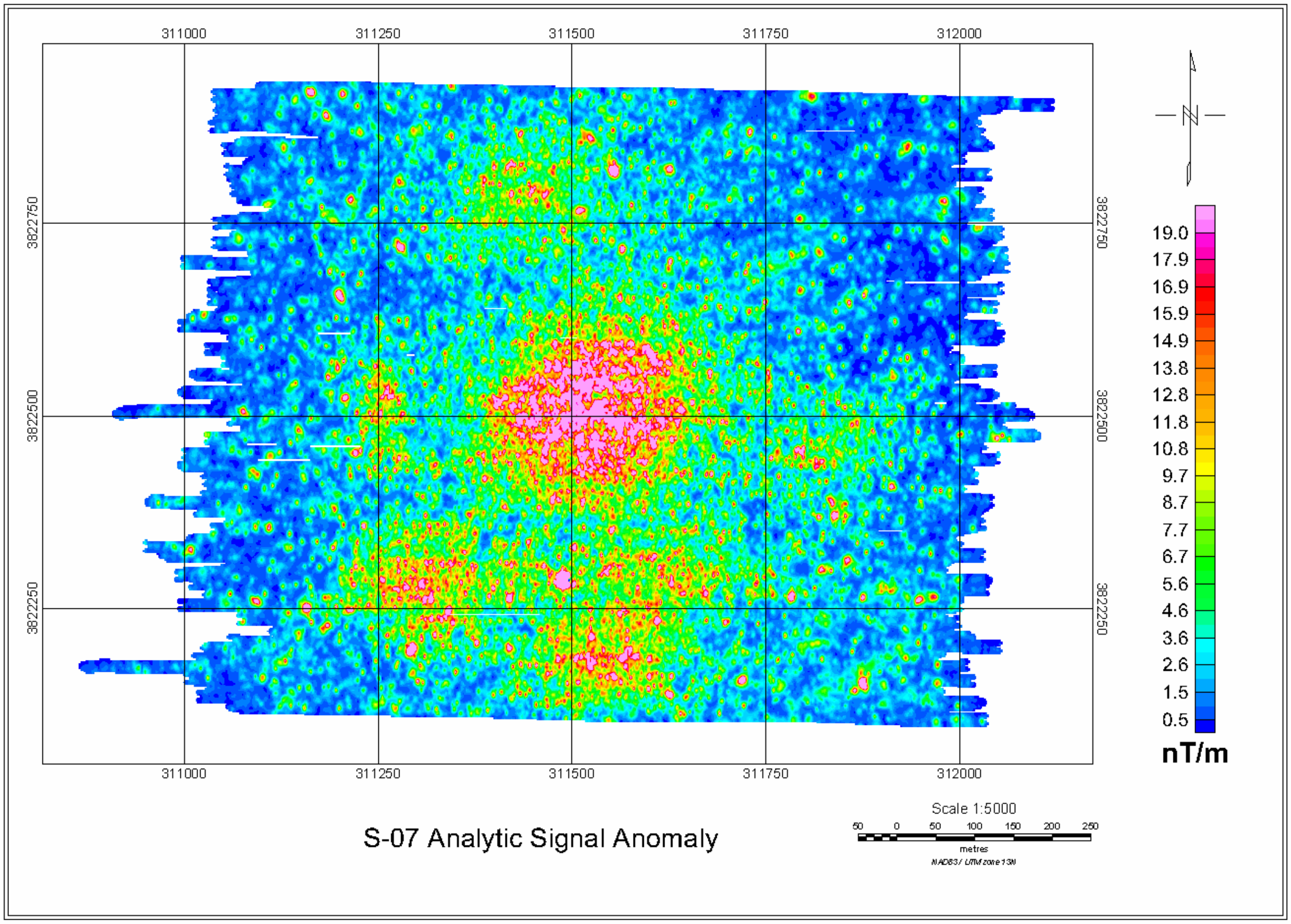

Figure 4.11 Analytic signal anomaly map, site S-07, for nominal 2 m survey height.

4.3.5 Sensor noise levels

Sensors behaved as expected during the demonstration, and sensor noise levels were at or below levels measured in previous demonstration surveys. Figure 4.12 shows raw and processed total magnetic field data for part of a line passing over the north end of site S-01. Even though this is some distance from the main target area, more than 25 000 nT of magnetic variation can be seen. Such variation can create difficulties in discriminating UXO from geological sources. Figure 4.13 shows a more detailed view of helicopter noise represented by a 100 m section of the same line shown in Figure 4.12. Helicopter-induced noise averages about 0.5 nT peak-to-peak over the section, which is almost entirely removed (reduced to approximately 0.1nT standard deviation) upon application of filters during processing.

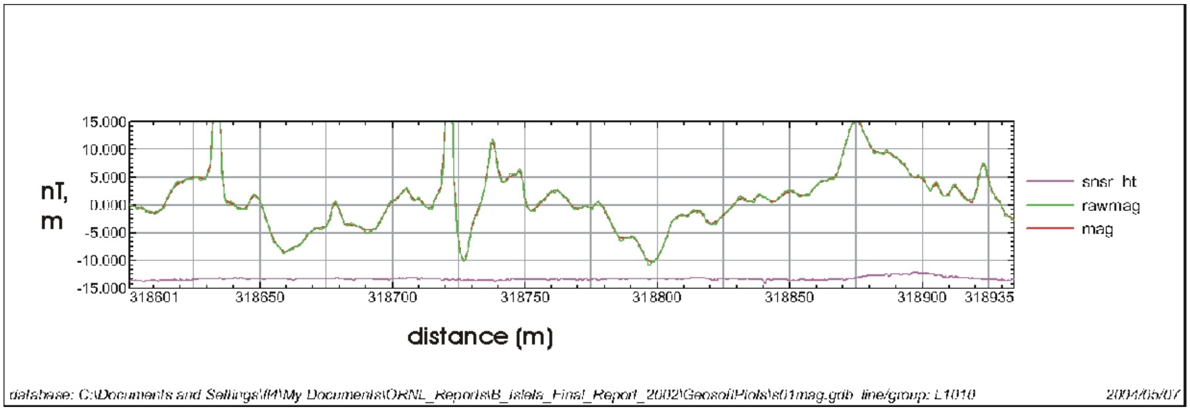

Figure 4.12 Sensor 1 data sample for a portion of survey line over north end of site S-01. Altitude varies from 0.9 m AGL to 2.8 m AGL.

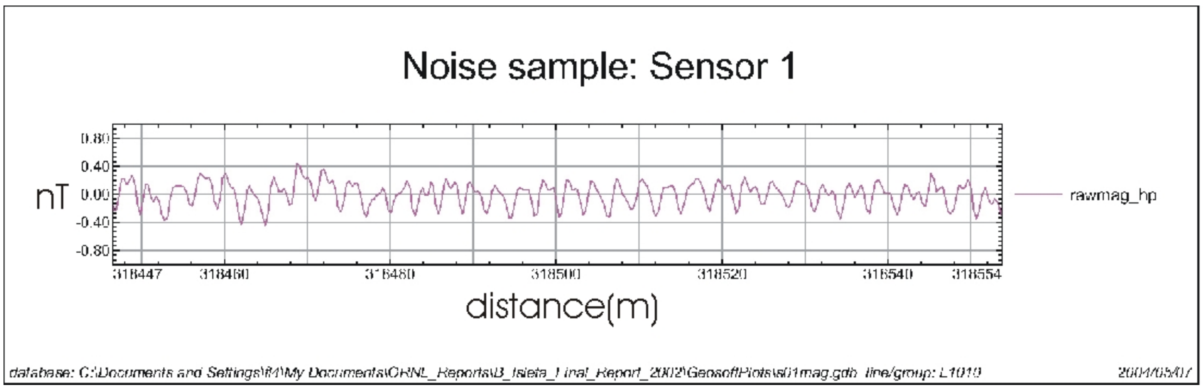

Figure 4.13 Noise on outboard sensor 1, as shown in high pass filter of 100 m segment of raw total magnetic field.

Noise levels of the eight sensors may be compared by applying a 20-point high pass filter to the raw magnetic data, then computing the standard deviation of a set of measurements over the same section of line, then multiplying the standard deviation by a normalizing constant to get the average peak-to-peak noise. Figure 4.14 shows the results of this comparison. Taking data from a line at the north end of site S-01, we find that the noise levels of six of the eight sensors fall near or below a value of 1.2 nT. Sensors 2 and 7 show somewhat higher noise levels. These two sensors are the inboard sensors on the port and starboard rear booms, respectively.

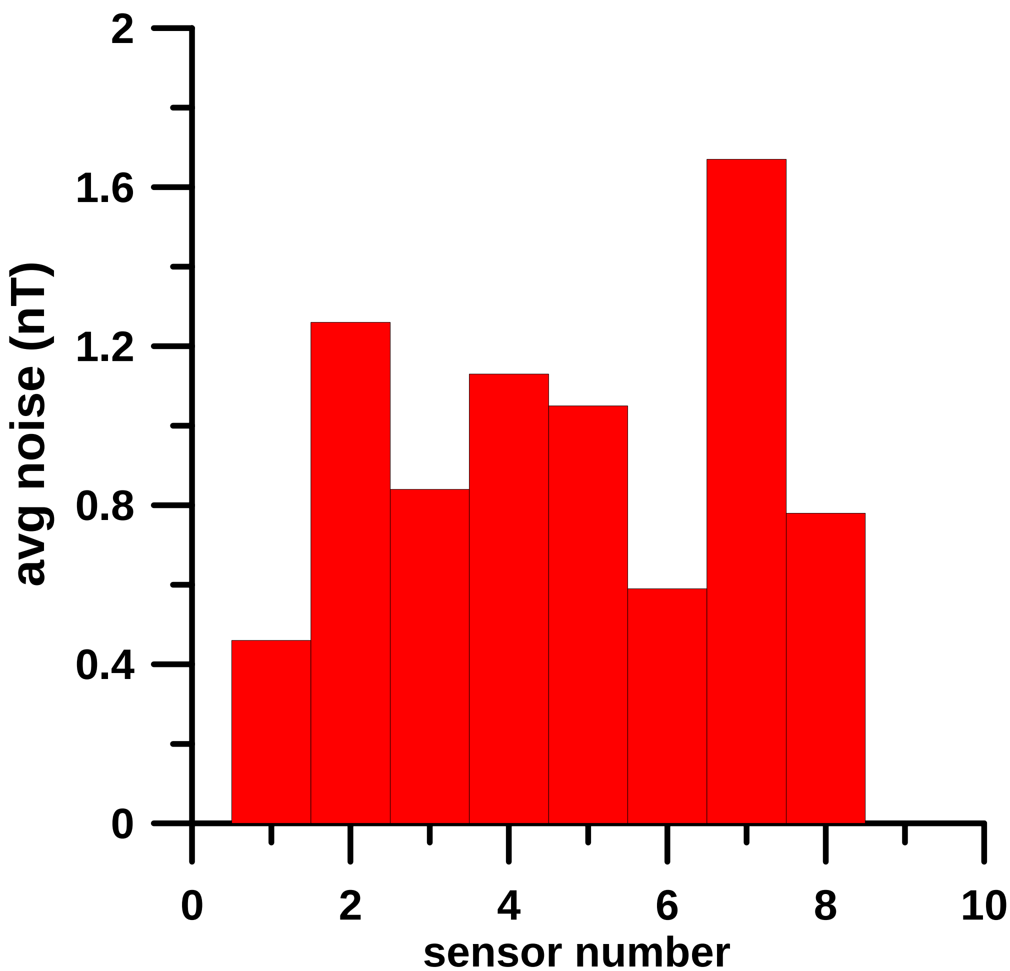

Figure 4.14 Average low altitude peak-to-peak raw noise levels of sensors 1-8 along line 1010 in S-01. Sensors 2 and 7, the inboard sensors on the rear booms, have higher noise levels than the other six sensors. Note that rotor noise levels will vary with aircraft heading and that filtering reduces these levels to approximately 0.1nT standard deviation.

4.3.6 Sensitivity

In the south central portion of site S-01, where the vast majority of digs were conducted, the practical limit at which the ORAGS-Arrowhead system was able to consistently detect UXO fragments is at a peak-to-peak total field anomaly amplitude of about 4.6 nT, or an analytic signal peak of 3.8 nT/m. Above these limits, most excavated anomalies containing intact UXO or UXO fragments were detected by the Arrowhead system. Below 4.6 nT (or 3.8nT/m analytic signal), there is a marked increase in false alarms.

4.3.7 Anomaly evaluation

Evaluation of anomalies used dig results from sites S-01, S-02, and S-07. Two anomaly lists were generated for each site. The first was an automated picking and classification system using a multivariate statistical routine. The second was a manual pick list using the DAS code to generate target parameters for manual classification. Positional accuracy was calculated by comparison of predicted dig locations with actual dig results from the excavations at each site. A summary of excavation results and miss distances is provided in Table 4.3.

At site S-02, 49 excavation targets were selected from the statistical pick list. Successful hits were declared for largely intact M38 bodies within an apparent 1m search radius. M38 fragments may or may not have been declared a successful hit at the discretion of the excavation team as documented in Appendix E. In total, 12 picks were declared successful. The distance between the listed location of the UXO and the statistical pick location ranged from 3cm to 73cm with an average miss distance of 31cm and a standard deviation of 23cm. Another 11 of the remaining anomalies were declared as “no finds” (including the magnetic rock), with the remaining 26 declared “no finds” with associated fragments.

The multi-variate statistical picks were classified based on their Mahalanobis distance (Swan and Sandilands, 1995). The priority is assigned in the target ID number. The excavation sites were chosen from a wide range of priorities from 199-1434. Successful hits showed no particular bias towards the high priority targets indicating that the prioritization operation still needs to be refined. The relatively low number of ‘no finds’ (11/49 or 22%) however indicates that the original automated selection process may have simply eliminated false anomalies from the start, leaving only high priority picks (ie only selects the equivalent of ESTCP classifications 1-3).

Of the 49 excavations, only 29 corresponded with ORNL anomalies characterized and prioritized using the DAS magnetic dipole inversion program (Nelson and McDonald, 1999), developed in conjunction with the MTADS project. Seven of these were declared successful hits, with the other five successful statistical hits falling within the 20 excavations that did not correspond to ORNL DAS picks. The miss distance for the DAS pick list ranged from 47cm to 196cm, with a mean of 102cm and a standard deviation of 48cm. The reason for the increased error in the DAS pick list is not apparent. A systematic offset of 25cm was observed in the DAS Northing offset, but altering this only reduced the mean offset by 5cm, while increasing the standard deviation and the maximum offset by 4cm each. No systematic offsets greater than 5cm were observed in the Easting or Northing miss distances.

Most items classed as UXO fragments occurred on the ground surface. The combination of prevalent surface UXO fragments and patches of rock or soil with high magnetic susceptibility (often described as ‘hot rock’) can produce a high number of magnetic ‘hits’ that can hinder the search for buried UXO. Because the magnetic response falls off with the cube of the sensor-target separation, small UXO fragments at the surface can produce anomalies that have similar magnitude as a larger ordnance item more deeply buried.

Area S-07 was flown and processed on the same day as S-02, but in spite of the excellent performance at S-02, ground crews had difficulty matching up ground features with airborne coordinates from the DAS pick list. As a result, no final dig coordinates were recorded and only a limited analysis can be completed for this area. Seven excavations yielded M38 fragments at the pick location (search radius unknown), and another six indicated M38 fragments within a 5 foot search radius. Ten locations were declared as "no finds" and the remaining 27 locations had magnetic signatures from an unspecified source, usually within a 6 foot search radius.

A sufficient number of excavations were carried out in 2003 at site S-01 (see the files 'S01_3-sys_matches102403.xls' and 'S01_groundtruth.xyz' on the CD accompanying this report) to permit a reasonably thorough analysis of the ORAGS Arrowhead data collected in this area. Originally, 9965 anomalies were picked and classified with the multi-variate statistical method, and a further 1023 were manually picked, inverted and classified using the DAS routine. Excavation lists were compiled the following year but were based on the combined ORAGS, aMTADS and gMTADS survey data rather than the 2002 survey data shown here. The center of investigation was taken from the gMTADS picks as this represented the most accurate starting location. For the purposes of declarations, ordnance and ordnance fragments were considered a successful hit. The 3-system area, or vehicular area, overlapped the 2002 survey block and included 337 excavations, of which 292 were declared as ordnance or ordnance frag. 191 statistical picks and 54 DAS picks overlapped with the excavation results within a 2m search radius. From these overlapping anomalies, 164 of the statistical picks and 45 of the DAS picks were declared successful hits. The miss distance on the successful statistical hits ranged from 7cm to 198cm, with a mean of 103cm and a standard deviation of 54cm. For the DAS picks, the range was 35-200cm with a mean of 120cm and a standard deviation of 46cm.

These figures produce detection statistics of 56% (164/292) and 15% (45/292) for the statistical and DAS picks lists. This is attributed to a high false negative response due to the higher airborne altitude and the relatively higher ordnance density near the target center. This is supported by the high success rate of the declared picks (few false positives). Within the individual pick lists, 86% of the statistical picks (164/191) and 83% of the DAS picks (45/54) were successful. It is conceivable that a lower threshold in the original anomaly selection would reduce the number of false negatives and improve the overall detection statistics.

A map of the geophysical data from S-01 with excavations shown as yellow circles is presented in Figure 4.15. Most were described in the remediation report as M-38 practice bomb fragments. The remainder consisted mostly of relatively intact M-38 practice bombs, 11kg (nominal weight) Mk-76 practice bombs, and smaller Mk-23 practice bombs. Of the 128 intact ordnance or ordnance fragments that were not detected, 99 were classed as M-38 fragments, and may have been too small for an airborne system to detect. Twenty-one of the undetected items were Mk-76 practice bombs, shown in Figure 4.16. At 11 kg, the Mk-76 should be expected to be within the limits of detection for the ORAGS Arrowhead system. However, the weights of the objects were not recorded, and excavation depths for the 21 undetected Mk-76 bombs averaged 75cm. This,

becomes the threshold depth of burial at which the magnetic signal for the Mk-76 decays to such an extent as to be indistinguishable from background variation for this survey area.

We have found that the miss distance for large ordnance items is often larger than for small items. We attribute this to a combination of (1) our system's positioning error, (2) our use of analytic signal peak to estimate target location, and (3) the assessment of item location upon excavation. The assessment of the position of, for example, a 500-lb bomb may be in variance by up to a meter based upon which part of the bomb—front, rear, center—is determined as its "location." In addition, the analytic signal anomaly of large objects may be several times the actual size of the source item, and in some cases may not be located directly over the body. These factors, when combined with our system's positional accuracy of about 1 m, can yield miss distances of up to 2.5 m for large ordnance items and for significant masses of scrap.

Table 4.3 Summary of excavation results and miss distances.

List	#matching digs	#successful declarations	miss dist (cm) (min-max, mean, stdev)
S-01 stat	191	164	7-198, 103, 54
S-01 DAS	54	45	35-200, 120, 46
S-02 stat	49	12	3-73, 31, 23
S-02 DAS	29	7	47-196, 102, 48
S-07	50	13	N/A

In comparing the detection capabilities of the system across the two areas, with two different excavation approaches and different teams, it is difficult to arrive at a single figure. At S-02, excavations were made directly from the statistical pick list without further ground follow-up, and success was declared only for UXO items, but not for fragments. At S-07 excavations were made from the DAS pick list. The lack of full ground truth makes it impossible to determine a true probability of detection. At S-01 excavations were made from a combination of three entirely different data sets, and success included detection of fragments. It is uncertain whether this constitutes a complete characterization of the area.

For purposes of comparison, we will use the S-01 conventions and include fragments as a successful declaration. In area S-02, this produces a total of 78% successful declarations (12 UXO plus 26 frag out of 49 excavations). Area S-01 had 164 successful declarations out of a list of 191 picks producing a total of 86%. There was, however, a high number of false negative responses in this area due to a high picking threshold that reduced the success rate to 56% when compared to the complete list of ground excavations (164 successful hits out of 292 ground declarations).

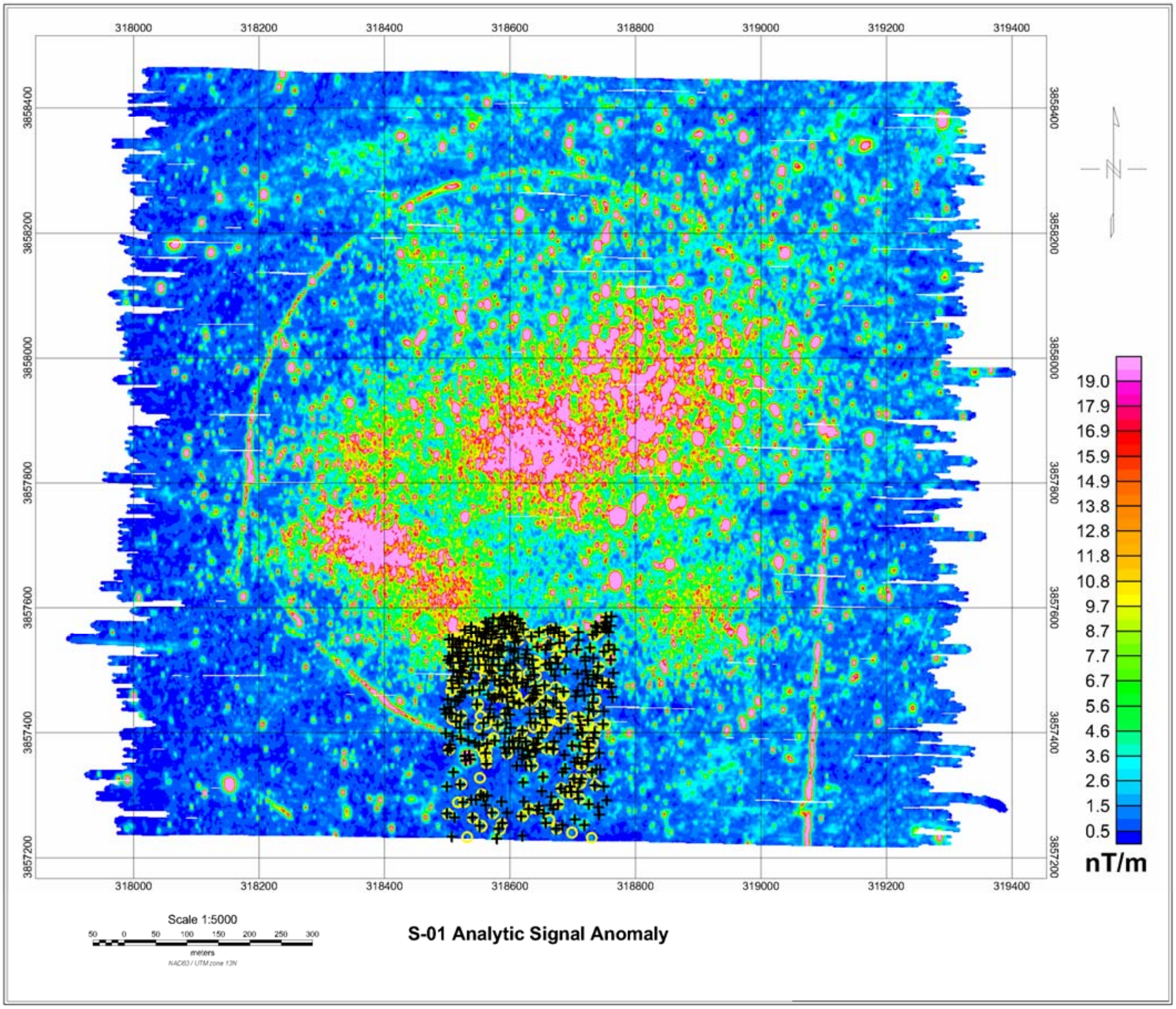

Figure 4.15 Analytic signal anomaly map of site S-01 showing locations of excavated ordnance (yellow circles) and ORAGS analytic signal peak locations (black '+' symbols). A larger version is provided in the digital attachments to this report.

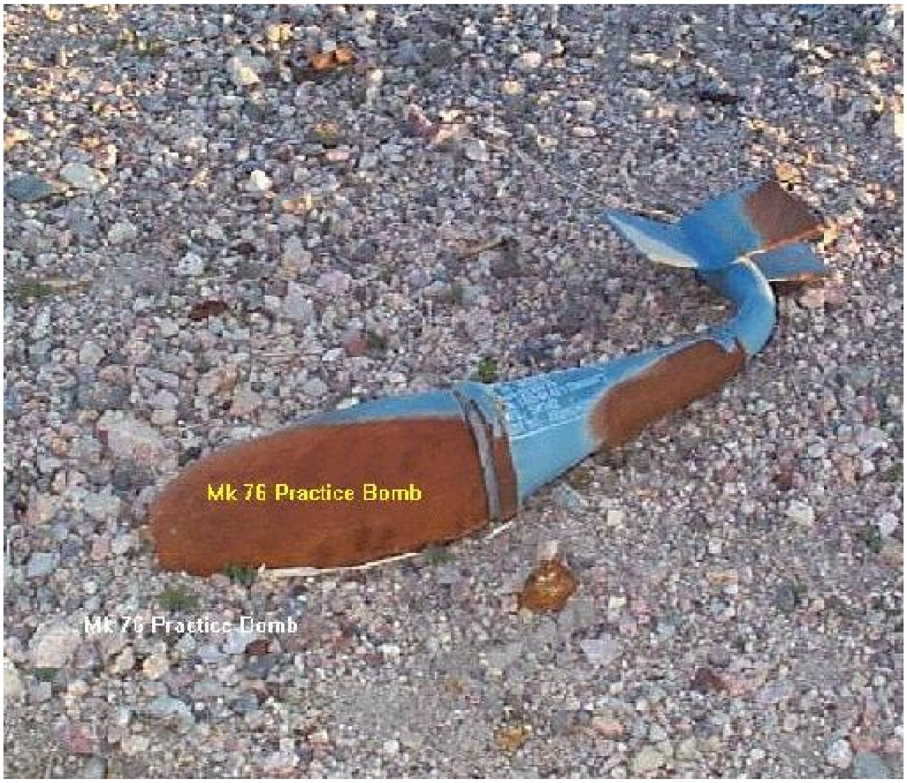

Figure 4.16 Mk-76 practice bomb, 11 kg nominal weight.

4.4 Technical Conclusions

The ORAGS-Arrowhead total field magnetometry system provided data adequate for defining target zones in test ranges having areas on the order of hundreds of hectares. The total field data were precise enough that positions of individual pieces of UXO scrap could usually be identified with an average 1m radial error. The ORAGS-Arrowhead system was able to collect data in excess of a rate of 103 acres per hour, a figure that includes turn around time at the ends of lines. Peak-to-peak noise levels in the raw magnetic data were within 1 nT in 5 of 8 sensors. In the two inboard sensors of the rear booms, noise levels exceeded 1 nT, but was less than 2 nT. Once filters were applied to noise induced by the blades and rotor, noise levels were reduced to 0.1-0.2 nT in all sensors.

In site S-01, results showed that only 56% of the successful excavations had an accompanying pick in the statistical list. These picks, however, represented 86% of the original list, indicating that very few false anomalies were detected and that a lower threshold would have improved the overall detection results. Area S-02 had a 78% success rate when including UXO plus fragments (as per area S-01), but the number of "no finds" was quite high. The location accuracy of the successful hits was very good, averaging 31cm. The reason for such high positional accuracy is not known. It is suspected that the orientation system was functioning more consistently than normal, and that this level of accuracy will become more common with a replacement system.

The relatively poor performance of the DAS pick locations (with respect to the statistical picks) is also unexpected. The statistical locations are limited in resolution to the grid cell size of the analytic signal, which is 0.5m. An error of +/-1 grid cell about this center point would produce a miss distance of approximately 1m. Area S-02 appears to have a higher degree of accuracy in that each pick was accurate within a single grid cell. This would produce a miss distance of approximately 0.5m and is comparable to that found in area S-02. Application of the DAS code to the airborne data is based on the positions of individual data points rather than grid cells, and outputs a location that is not limited by gridding. The results should therefore produce a smaller miss distance. This was not the case. The reason for this inconsistency is unclear, but is probably due to low signal-noise ratios in the anomaly signatures producing unstable results.

5 Cost Reporting

Cost information associated with the demonstration of all airborne technology, as well as associated activities, were closely tracked and documented before, during, and after the demonstration to provide a basis for determination of the operational costs associated with this technology. It is important to note that the costs for airborne surveys are very much dependent on the character, size, and conditions at each site; ordnance objectives of the survey (e.g. flight altitude); type of survey conducted (e.g. high-density or transects); and technology employed for the survey (e.g. total field magnetic) so that a universal formula cannot be fully developed. For this demonstration, the following table contains the cost elements that were tracked and documented for this demonstration. These costs include both operational and capital costs associated with system design and construction; salary and travel costs for support staff; subcontract costs associated with helicopter services, support personnel, and leased equipment; costs associated with the processing, analysis, comparison, and interpretation of airborne results generated by this demonstration. As the Pueblo of Isleta survey was conducted in the same mobilization as the Pueblo of Laguna survey, many cost items were reported in the Pueblo of Laguna survey final report (ORNL, 2004) and have been duplicated in the Pueblo of Isleta report.

Table 5.1 Survey Cost Assessment

Cost Category	Sub Category	Details	Quantity	Cost[1] (in $)
Pre-Survey	Site Characterization	Site inspection (includes	4 days	$8,752
(Start-up)		travel)		
		Mission Plan preparation	5 days	$8,845
		& logistics		
	Mobilization	Calibration Site		
		development (includes	2.5 days	$9,474
		pre-seed and post-seed		
		ground-based surveys)		
		Equipment/personnel		
		transport (includes travel)		
		Helicopter/personnel	2 days	$8,660
		transport (includes travel)		
		Unpacking and system		
		installation	1.5 days	$10,974
		System testing &	(11 hours	
		calibration	airtime)	
			0.75 day	$4,013
			0.75 day	$5,678
Pre-survey subtotal				$56,396
Capital Equipment[2]	Cs-magnetometers	$122,200 total cost	8 each	$2,444
	GPS	$15,500 total cost	1 each	$310
	Booms and mounting	$36,500 total cost	1 set	$6,570
	Orientation system	$16,600 total cost	1 each	$332
	Fluxgate magnetometer	$5,300 total cost	1 each	$106
	Navigation system	$5,200 total cost	1 each	$104
	Laser Altimeter	$7,300 total cost	1 each	$146
	Data mgt console	$31,200 total cost	1 each	$624
	Magnetic base station	$15,100 total cost	1 each	$302
	GPS base station	$15,600 total cost	1 each	$312
	PCs for data processing & analysis	$3,450 total cost	2 each	$69
	Shipping Cases	$4,750 total cost	6 each	$95
	Trailer	$3,600 total cost	1 each	$72
Capital subtotal				$11,486

Operating Costs	Equipment Rental Data acquisition Operator labor Data processing Field support/management Maintenance Hotel and per diem Fuel Truck Airport Landing Fees	Spare magnetometers GPS equipment Helicopter time, including pilot and engineer labor - Geophysicist Engineer Geosoft software maintenance[3] Survey team in New Mexico Remote re-fueling	2 each 1 each 8 days (23 hours airtime) 8 days 8 days (48 hours labor) 8 days (48 hours labor) - 8 days 8 days	$840 $950 $17,378 $175 $32,340 $37,149 $248 $4,016 $200
	Data analysis and interpretation	Geophysicist	15 days	$23,100
	Project management		8 days	$14,152
	Reporting and documentation		15 days	$23,100
Operating cost subtotal				$153,648
Post-Survey	Demobilization	Disassembly from helicopter, packing, and loading for transport Equipment/personnel transport (includes travel) Helicopter/personnel transport (includes travel)	1 day 2.5 days 2 days	$4,514 $8,660 $10,974
Post-survey Subtotal				$24,148
Indirect Environmental Activity Costs	Environmental and Safety Training	8-hour HAZWOPR (includes the course cost)	1 day	$3,878
Miscellaneous	Department of Energy Federal Acquisition Cost (FAC)	3% of project total; Congressionally-mandated charge for administering the Work-for-Others (WFO) program		$7,487
Total Costs				$257,043

Footnotes to cost table:
[1]Includes all overhead and organization burden, fees, and associated taxes
[2]Capital costs are apportioned at 20% of the total cost for this project, but including only in the Laguna portion of the survey project; all capital equipment was used for several projects during the course of the year in which this project occurred
[3]Geosoft software costs include the cost of 1 license and the UX-Detect module. The license cost is apportioned at 20% of the total cost for this project in a similar fashion to the capital equipment costs, but is included in the Laguna portion of the survey project only.

Note that, unlike the apportionment of capital costs, certain costs here are duplicated in the Pueblo of Laguna survey report. In particular, mobilization and demobilization were declared in the Laguna survey project report. Including capital acquisitions, mobilization, and demobilization, the cost per acre for this survey was $323/ac.

6 Implementation Issues

6.1 Environmental Checklist

In order to operate, each system must have Federal Aviation Administration approval (Supplemental Type Certificate). The required testing and evaluation performed in Toronto before mobilization to New Mexico has been completed. In addition, ground crews are required to complete the 40-hour HAZWOPR course and to maintain their annual 8-hour refreshers for operation at most UXO sites.

6.2 Other Regulatory Issues

There are no additional regulatory requirements for operation at either site in New Mexico.

6.3 End-User Issues

The primary stakeholders for UXO issues at the Pueblo of Isleta sites in New Mexico are the members of the Pueblo of Isleta Tribe, other residents of Pueblo of Isleta Reservation, and State of New Mexico regulatory authorities. Airborne UXO surveys have been designed to accommodate the limitations and needs of each site. Larger scale surveys have been proposed and discussed with several sites. USAESCH has assisted in efforts to commercialize the existing technology and this has led to shared operation with one contractor for engineering evaluation/cost analysis (EE/CA) activities. As new systems are developed and proven, they will enter into the same cycle of application and commercialization.

7 References

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8 Points of Contact

Points of contact are given below in Table 8.1.

Table 8.1 Points of Contact

Name	Organization	Phone	Project Role
Gary Jacobs	ORNL	865-574-7374	Division Director
David Bell	ORNL	865-574-2855, 865-250-0578 (cellular)	Project Manager
Bill Doll	ORNL	865-576-9930	Technical Manager
Jeff Gamey	ORNL	865-574-6316 865-599-0820 (cellular)	Operations Manager
Les Beard	ORNL	865-576-4646	Geophysicist
Scott Millhouse	USAESCH	256-895-1607	Project Lead
Jim Piatt	Pueblo of Isleta	505-869-5748	Environment Department Director
Dan Munro	National Helicopters	905-893-2727	Helicopter Contractor President

Appendix A
Analytical Methods Supporting the Experimental Design

A.1 Statistically based UXO discrimination

We began investigating statistically-based discrimination methods after an analysis of dig results based on data collected at the former Badlands Bombing Range (BBR) in South Dakota showed statistical differences between ordnance and non-ordnance. In no instance was the statistical difference so strong that a single parameter could predict whether the source of an anomaly was UXO or not, but the possibility for discrimination increased as more parameters were considered. We used a routine developed to our specifications by Geosoft to rapidly identify and characterize anomalies above a given threshold from an analytical signal map. From these peaks we identified the associated magnetic field anomaly and sensor altitude, and computed a number of parameters that could be used directly or otherwise combined as statistically relevant predictors. From this point we used two different approaches for discrimination—a univariate and a multivariate methods.

A.1.1 Univariate method (not used for Isleta data)

The univariate method relies on correlations from dig results based on airborne magnetic data collected at two different sites: an East Coast site and BBR. Both sites were geologically ‘clean’ in that neither contained basaltic rock or magnetic soils that could complicate any interpretations. We chose six parameters showing correlation with known UXO, and at each anomaly location evaluated whether the parameters fell within the range of the majority of known measured UXO. Each of the six parameters was scored zero if the parameter fell outside a specified range, and one if it fell within the range. For example, almost all ordnance in our known sample pool yielded peak-to-peak magnetic anomalies between 1.0 and 80 nT. Any anomaly falling outside this range was scored zero, as non-UXO. The six characteristics were scored and summed, so that items could have a value ranging from 6 (all characteristics in the range of UXO) to zero (all characteristics outside the range for UXO). The six parameters used in the univariate analysis were analytic signal amplitude, magnetic anomaly peak-to-peak magnitude, the distance between the magnetic anomaly peak and low, the ratio of the positive magnetic anomaly lobe to the peak-to-peak magnitude, the estimated source depth, and the angle between magnetic north and the line connecting the positive and negative lobes of the magnetic anomaly (denoted theta).

A.1.2 Multivariate method

Multivariate analysis should provide more information than the univariate approach described above as long as some or all of the variables are correlated, and if the number of known samples is large enough to obtain reliable statistics. The parameters must also be appropriately normalized to remove the effects of different magnitudes for the given parameters. We derived a vector of standard mean parameters $\mu 0$ from a set of measurements over known ordnance items,

and compute the symmetric covariance matrix S from the covariances computed for the different variable combinations. The statistical similarity between the known ordnance and the parameter vector x associated with an unknown is given by the Mahalanobis distance (Swan and Sandilands, 1995)

$$D = \{(x - \mu 0)T\ S\text{-}1\ (x - \mu 0)\}\ 1/2. \qquad (1)$$

The smaller the Mahalanobis distance the more closely the unknown resembles ordnance from the known pool of items. The vectors x and μ0 each have five entries: analytic signal peak, the magnitude of the negative lobe of the magnetic anomaly, the ratio of the positive magnetic anomaly lobe to the peak-to-peak magnitude, the ratio of the distance between the magnetic anomaly positive peak and the analytic signal peak to the instrument height added to the estimated source depth, and theta, as described in the univariate section. The differences in the variables used in the two methods of analysis occurred because the univariate analysis was done prior to a more complete statistical review of the data, which led to the multivariate approach.

A.2 Model-based inversion of magnetic data as an aid to discrimination

Magnetic fields in the vicinity of UXO can often be reliably estimated using a model based on a magnetic dipole. The DAS software (McDonald and Nelson, 1999) is based on this model. DAS does not perform discrimination, but rather is an aid to the interpreter, who subjectively performs the discrimination task. DAS requires as input a set of coordinates (x,y,z) and a magnetic total field measurement at each coordinate. The software constructs a grid of the total field data from which the interpreter can select individual anomalies as likely UXO targets. The user selects a boundary around the anomaly that includes some area outside the main anomaly, and the DAS code searches for a dipole model that best fits the selected data. Output are estimates of the moment of the magnetic dipole, its length, orientation, burial depth, and goodness of fit. From the returned parameters, an experienced interpreter can make a reasonably well-informed judgment as to whether or not the source of the anomaly is intact ordnance, scrap, or non-UXO related.

Appendix B
Quality Assurance Project Plan (QAPP)

At the time of this survey, we were not required to have a QAPP in place, nor had ESTCP published the current guidelines for QAPP documentation (ESTCP Final Report Guidance for UXO Projects, Revision 2, April 2002). We nevertheless developed our own QA/QC procedures that were followed through this and other projects. These fall into three main categories: operational QA/QC, system QA/QC, and data QA/QC.

Under the category of operational QA/QC:
Site visit preliminary to survey to assess appropriateness of site for helicopter geophysical surveying;
De-gaussing of helicopter rotor to decrease magnetic noise produced by this component;
Review of GPS almanac to assess best times of the day for surveying;
Emplacement of a calibration grid for daily system checks;
A morning meeting to coordinate each day's activities;
An evening meeting to review activities and safety issues.

Under the category of system QA/QC:
Installation of booms under the supervision of the pilot and engineer, and subsequent double-checking of all mounts and bolts;
Daily helicopter inspection and maintenance by pilot and engineer;
Ground tests of system after installation (checks to determine if all magnetometers are operating and have been connected in the correct order, and an impulse test to determine the lag between magnetometers and fluxgate);
An initial check flight after installation.

Under the category of data QA/QC:
An extensive test flight to evaluate the effects of pitch, roll, and yaw on the magnetometers, from which we can calculate compensation coefficients, and to examine the high altitude noise levels of the magnetometers.
Daily inspection of diurnal magnetic activity at a base station magnetometer;
Visual inspection of all data;
Daily plots of flight path and laser altitude;
Adherence to the data processing flow, described in section 3.6.6;
Daily production of digital magnetic maps;
Archiving of all materials: flight logs, digital materials, and report.

Appendix C
Health and Safety Plan

This document represents the health and safety plan applied to field operations in New Mexico.

C.1 Aircraft Base of Operations

Albuquerque International Sunport
2200 Sunport Blvd. SE
Albuquerque, N.M. 87106
Fixed Base Operator: Cutter Flying Service, Inc.
Phone: 505-842-4184

The base of operations for all aircraft activities was Albuquerque International Sunport. The aircraft were stored and some refueling activities will occur at this location. Other refueling activities will occur remotely through use of a fuel truck provided by National Helicopters, Inc. No direct aircraft support (e.g., housing, fuelling, etc.) is requested from the Department of Defense.

C.2 Communications

Air-to-ground and ground-to-ground communications occurred using two-way VHF radios provided by ORNL and National Helicopters. Radios broadcasted at 118 - 135 MHz. All other communications were via cellular telephones.

C.3 Schedule Constraints and Crew Rest

C.3.1 Schedule Constraints

During aviation missions, activities can occur that are uncontrollable by the survey team and cause a delay of data acquisition. These activities may result in missed data acquisition windows or the loss of entire days of data acquisition.

C.3.2 Crew Rest

Crew rest will follow the guidelines prescribed by FAA regulations. Restrictions are placed on both the pilot's in-air flight-time and duty-time.

C.4 Aircraft

Bell 206L Long Ranger III Helicopter National Helicopters, Inc.
Color scheme: White with midnight blue and 11339 Albion Vaughn Road
light blue accents
Kleinburg, Ontario, Canada
Serial Number: 45784
Phone: 905-893-2727
Tail Number: C-FNHG

C.5 Statement of Risks

Airborne geophysical surveys are designed to be conducted with minimal risk to personnel. Safe operation of the aircraft is the direct responsibility of the pilot, who will determine the minimum safe flight altitude and local weather conditions for safe flying on an ongoing basis. The mission was flown under all applicable Federal Regulations.

Most ground activities were limited to routine working conditions; however certain field activities will expose personnel to summer heat and prairie wildlife. Precautions against the heat include drinking plenty of water, using sunscreen, and taking breaks as needed. Precautions against the wildlife include wearing hiking (or similar) boots and minimization of exposure to that environment. In addition, the two-man rule was in effect for all on-site field activities.

For additional risk-related information, consult the Operational Emergency Response Plan contained in Appendix B of this document.

C.6 Emergency Notification

Emergency action plans are included in the Appendix of this document. In the event of an emergency, staff will first request assistance, then provide appropriate first aid measures until emergency assistance arrives. As soon as emergency assistance has been obtained, the following people were to be notified in sequence based on availability:

Mr. David Bell, ORNL Project Manager
Cellular: 865-250-0578
Office: 865-574-2855
Dr. Bill Doll, ORNL Technical Manager
Cellular: 865-599-0820
Office: 865-576-9930
Mr. Jeff Gamey, ORNL Operations Manager
Cellular: 865-599-0820

Office: 865-574-6316

Mr. Scott Millhouse, USAESCH Program Manager

Office: 256-895-1607

Mr. Dan Munro, National Helicopter, President

Office: 905-893-2727

Dr. Steve Hildebrand, ORNL Environmental Sciences Division Director

Office: 865-574-7374

Home: 865-966-6333

Each organizational member of the project team is responsible for flow-down of communications within the respective organization in the event of an incident or emergency (e.g. notification of next-of-kin by ORNL Environmental Sciences Division Director if ORNL staff is involved in an emergency situation, etc.). Any member of the project team, in the event of an emergency situation, shall not contact persons other than those designated in the above listing.

C.7 On-Site Ground Emergencies

In the event of an emergency that occurs on-site:

Telephone local emergency response organizations via 911, if needed.

2) Conduct appropriate first aid.

3) Notify managers, as listed above in sequence. The ORNL Project Manager has jurisdiction for all on-site emergency activities. If the ORNL Project Manager is not available, the ORNL Technical Manager has jurisdiction.

4) The pilot has jurisdiction for emergency response when the aircraft is airborne, has crashed (if able), or has an emergency situation on the ground.

5) In the event of a catastrophic accident, the ORNL Environmental Sciences Division Director shall be notified immediately, and included in all response team activities, including communication, emergency response, and reporting.

C.8 Off-Site Ground Emergencies

In the event of an emergency that occurs off-site:

1) Assess the urgency of the emergency.

2) Telephone local emergency response organizations via 911, if needed.

3) Conduct appropriate first aid while awaiting professional assistance.

4) Notify managers, as listed above in sequence. The ORNL Project Manager has jurisdiction for all off-site emergency activities. If the ORNL Project Manager is not available, the ORNL Technical Manager has jurisdiction.

5) The pilot has jurisdiction for emergency response when the aircraft is airborne, has crashed (if able), or has an emergency situation on the ground.

6) In the event of a catastrophic accident, the ORNL Environmental Sciences Division Director shall be notified immediately, and included in all response team activities, including communication, emergency response, and reporting.

C.9 In-Air Emergencies

In-air emergencies were to be handled via standard aircraft emergency protocol, including radio contact with the Rapid City Regional Airport. The pilot has jurisdiction for all emergency response activities and requirements when the aircraft is airborne. Follow-up telephone/radio notification to the emergency response personnel listed in Section 11.0 were to be made as soon as possible.

Appendix D
Data Storage and Archiving Procedures

General

Digital data are on the CD accompanying this report. Included are: (1) readme files, (2) a copy of the final report in *.DOC format, (3) digital copies of the total field and analytic signal maps from each area flown (S-01, S-02, S-07) in TIF format, (4) dig lists in ASCII format, (5) geophysical data files in ASCII format, (6) ORNL analysis files, and (8) excavation and remediation results.

Geophysical Data

The data included with this report is ASCII text and conforms to the format described in the "Area_Data_Readme.txt" file on the CD-ROM provided. Files are named according to area surveyed: S01_MAG.XYZ, S02_MAG.XYZ, S07_MAG.XYZ. Coordinates are UTM Zone 13 N, NAD83 (Continental US).

ASCII text file format is comma delimited in the following order:

Column 1: Easting coord (m)
Column 2: Northing coord (m)
Column 3: Line ID
Column 4: laser altimeter (m)
Column 5: raw magnetic signal (nT)
Column 6: residual total magnetic field (nT)

Dig Lists

The dig list information is saved in an ASCII text format file. Numerous dig lists were required of us during the project. Accompanying this document are ASCII files comprising locations for excavation at sites S-01, S-02, and S-07 on the Pueblo of Isleta, New Mexico. The data from which the choices were made comes from a 2002 ORNL helicopter geophysical survey. The locations chosen are derived from dipole fitting using the DAS software, from multivariate statistical analysis, from univariate statistical analysis, and from visual inspection of the raw data. Coordinates are given in UTM Zone 13 N (meters) using a NAD83 (Continental US) datum, as well as in geographical latitude/longitude. For each of the areas N09 and N10 there are 5 dig lists, described below using site N10 as an example.

S01_DAS1.XLS— Targets generated using DAS software and prioritized 1-6 according to likelihood of being UXO (1= highest likelihood, 6=lowest).

S02_DAS.XLS— Targets generated using DAS software and prioritized 1-6 according to likelihood of being UXO (1= highest likelihood, 6=lowest).

S07_DAS.XLS— Targets generated using DAS software and prioritized 1-6 according to likelihood of being UXO (1= highest likelihood, 6=lowest).

S01_STATPICKS.XYZ— Targets generated using multivariate analysis and ranked according to statistical semblance to UXO.

S02_ STATPICKS.XYZ— Targets generated using multivariate analysis and ranked according to statistical semblance to UXO.

S07_ STATPICKS.XYZ— Targets generated using multivariate analysis and ranked according to statistical semblance to UXO.

Images

Geophysical anomaly maps (total field residual and/or analytic signal) for each area (S-01, S-02, and S-07) are provided as image files in TIF formats. The TIF images have been saved at 200dpi at the scale labeled on each map. These files have the form Area_TF.TIF and Area_AS.TIF.

Remediation Results

Government excavation results are provided in Excel files labeled:
'S01_3-sys_matches102403.xls', 'Remediation Results for Targets S2 and S7.xls', 'S02_DAS_Remediation.XYZ', and 'S01_Groundtruth.xyz'.

Appendix E
Excavation Results from S-02 and S-07

Area S-02

ID	UTM_N (stat pick)	UTM_E (stat pick)	Depth (m)	Analytic Signal	Depth (ft)	Description
S2-1	3839998.00	325915.50	0.40	42.4	1.3	0 Find M-38 Body fragments (surface) 3 east of grid point
S2-2	3840505.00	325758.00	0.71	40.4	2.3	0 Find M-38 Body fragments (surface) about 8 ft. east of grid
S2-3	3840212.50	326241.50	0.00	37.3	0.0	0 Find @ grid M-38 fragment 3 ft. NE of grid point
S2-4	3840406.00	325896.00	0.06	33.9	0.2	M-38 Bomb body fragment 1 ft. N of grid point- surface
S2-5	3840475.50	325986.50	0.37	31.5	1.2	0 Find
S2-6	3840256.50	326346.50	-0.06	29.0	-0.2	M-38 Fragment 1 ft. N of grid point
S2-7	3840611.50	325925.50	-0.08	27.2	-0.3	0 Find
S2-8	3840515.00	325797.50	0.55	26.8	1.8	0 Find
S2-9	3840382.50	326022.50	-0.13	26.6	-0.4	0 Find Surface fragment 4 ft. from grid point south
S2-10	3840400.50	326338.50	-0.25	24.6	-0.8	M-38 fragment on surface 3 ft. N of grid point
S2-11	3840226.00	326279.00	0.16	23.4	0.5	M- 38 Fragment M-38 bomb body fragment on surface of grid point
S2-12	3840376.50	326291.00	-0.14	23.3	-0.5	0 Find M-38 Fragments 3 ft. E & W of grid point
S2-13	3840139.50	326247.50	-0.23	22.8	-0.8	M-38 Fragment 1 ft. S of grid point
S2-14	3840283.00	325742.00	0.06	21.7	0.2	0 Find magnetic signature 8 ft. S of grid point
S2-15	3840199.50	325735.50	0.60	21.6	2.0	0 Find
S2-16	3840037.00	326239.00	0.10	21.3	0.3	M-38 Fragments M-38 fragments @ 6", 18" and 36" on surface
S2-17	3840008.00	326207.50	-0.39	21.3	-1.3	0 Find M-38 bomb body on surface 3 ft. E of grid point
S2-18	3840024.00	326163.00	0.06	20.7	0.2	Magnetic rock Grid point surrounded by voleanic rock-magnetic
S2-19	3840151.50	326357.50	0.31	20.4	1.0	0 Find M-38 fragmentson surface8 ft. E of grid point
S2-20	3840305.00	326376.00	-0.05	20.1	-0.2	0 Find M-38 Fragment on surface 4 ft. E of grid point

S2-21	3840247.50	326372.00	-0.32	20.1	-1.0	M-38 Fragment 1 ft. N of grid point
S2-22	3840607.50	325867.50	0.23	20.0	0.8	0 Find magnetic signature 4 ft. E of grid point
S2-23	3840381.50	325776.50	-0.56	20.0	-1.8	0 Find M-38 fragment on surface 3' E of grid point
S2-24	3840183.50	326111.00	0.66	19.7	2.2	M-38 fragments surface around grid point cluttered w/ M-38 fragments
S2-25	3840090.50	326273.00	0.11	19.6	0.4	0 Find M-38 Bomb body fragments on surface 5 ft. S of grid point
S2-26	3840052.00	326390.00	-0.28	19.5	-0.9	0 Find
S2-27	3840417.50	325841.00	0.17	18.6	0.6	0 Find magnetic signature 4 ft. N of grid point
S2-28	3840495.50	325799.50	-0.03	18.4	-0.1	0 Find M-38 Bomb fragments on surface 8 ft. E of grid point
S2-29	3840254.00	326045.50	0.03	18.2	0.1	M-38 fragments 6" S of grid point M-38 fragments scattered all around grid point
S2-30	3840088.00	326063.00	0.21	18.0	0.7	0 Find
S2-31	3840377.00	326337.50	-0.28	17.8	-0.9	0 Find M-38 fragment on surface 2 ft. E of grid point
S2-32	3839927.50	326183.00	-0.34	17.4	-1.1	0 Find M-38 fragment on surface 8 ft.E of grid point
S2-33	3840358.50	325972.50	0.39	17.3	1.3	0 Find
S2-35	3839987.00	326075.00	-0.39	16.6	-1.3	0 Find M-38 fragment on surface 6 ft. E of grid
S2-36	3840179.50	326120.00	0.18	16.5	0.6	0 Find surface area around grid point cluttered w/ M-38 fragments
S2-37	3840426.00	325771.00	0.09	16.3	0.3	0 Find surface fragment 6 ft. E from grid point
S2-38	3840068.50	326153.50	0.75	16.1	2.5	M-38 fragment located in N end of hole M-38 fragment on surface 5' E of grid point
S2-39	3840390.00	326292.00	0.53	16.1	1.7	M-38 Fragments
S2-40	3840250.50	326247.00	0.32	16.0	1.0	0 Find M-38 fragment on surface 3' NE of grid point
S2-41	3840018.50	326383.50	-0.58	15.9	-1.9	0 Find M-38 fragment on surface 3' S of grid point
S2-42	3840051.50	325738.00	0.72	15.5	2.4	M-38 Fragment M-38 fragment on surface 6' S of grid point
S2-43	3840361.50	326334.00	0.31	14.3	1.0	0 Find M-38 Fragment on surface 4 ft. E of grid point
S2-44	3839938.00	326082.00	0.13	14.1	0.4	0 Find M-38 fragment 6' NE of

						grid point
S2-45	3840017.00	326233.00	0.45	13.6	1.5	0 Find M-38 fragments on surface 5' E of grid point
S2-46	3840152.00	326142.50	0.11	13.4	0.4	0 Find surface area around grid point cluttered w/ M-38 fragments
S2-47	3839933.50	326190.50	0.27	13.0	0.9	0 Find
S2-48	3840513.50	325857.00	0.46	12.3	1.5	0 Find
S2-49	3840054.00	326227.50	0.50	11.4	1.6	0 Find M-38 fragment on surface 4 ft. N of grid point
S2-50	3840496.00	325889.00	0.14	11.2	0.5	0 Find

Area S-07

ID	UTM_N (DAS pick)	UTM_E (DAS pick)	Depth (m)	Analytic Signal	Depth (ft)	Description
S7-1	3822202.66	311333.63	0.30	23.0	1.0	Empty 0 find 3 ft. W of grid point at 1 ft. M-38 fragments
S7-2	3822516.56	311823.42	0.47	22.6	1.5	M-38 fragments
S7-3	3822559.50	311265.77	0.59	21.6	1.9	Empty 0 find magnetic singature 7 ft. S and W of grid point.
S7-4	3822914.18	311510.47	0.41	20.2	1.3	0 find @ 22' M-38 fragments found @ a depth of 20" 5 ft. S of grid point.
S7-5	3822357.93	311205.79	0.25	19.4	0.8	Empty 0 find magnetic singature 5 ft. S and E of grid point.
S7-6	3822683.59	311228.81	0.55	17.9	1.8	Empty 0 find magnetic signature 5 ft. S of grid point
S7-7	3822176.23	311304.71	0.94	17.9	3.1	Magnetic soil 3'W of grid point @ 1 ft. M-38 fragments
S7-8	3822513.98	311785.76	0.38	16.7	1.2	0 find
S7-9	3822200.64	311261.74	0.88	16.4	2.9	0 find
S7-10	3822320.77	311962.15	0.81	16.3	2.7	0 find magnetic signal 6' S and E of grid point.
S7-11	3822293.04	311438.59	1.42	16.3	4.7	M-38 fragments @ 16" 0 find @ 4 ft. 4 inch.
S7-12	3822346.05	311136.36	0.69	16.0	2.3	M-38 fragments
S7-13	3822448.18	311744.32	1.27	15.5	4.2	0 find magnetic signature 5 ft. E of grid point.
S7-14	3822770.18	311652.48	-0.08	15.4	-0.3	0 find No magnetic signature
S7-15	3822787.89	311594.11	0.76	14.6	2.5	M-38 fragments located @ 11" More fragments at 24"
S7-16	3822780.07	311731.22	0.54	14.4	1.8	Empty 0 find
S7-17	3822630.25	311647.96	1.19	14.2	3.9	Empty 0 find
S7-18	3822220.83	311639.70	0.20	13.6	0.7	0 find M-38 fragments 5 ft. N and 6' W and S of grid point surface fragment.
S7-19	3822406.14	311288.28	0.81	13.6	2.7	Empty 0 find magnetic signature 6 ft. E of grid point
S7-20	3822199.95	311453.38	0.92	13.4	3.0	Magnetic soil
S7-21	3822351.02	311716.13	0.95	13.3	3.1	0 find magnetic signature 5 ft. E of grid point.
S7-22	3822313.91	311650.84	1.07	13.3	3.5	0 find
S7-23	3822728.04	311541.27	0.87	13.0	2.9	Anomaly 4' E of target.
S7-24	3822695.57	311742.72	1.19	12.9	3.9	Empty 0 find magnetic signature 6 ft. Eof grid point.
S7-25	3822821.93	311343.21	0.41	12.6	1.3	Empty 0 find magnetic signature

						6 ft. SEof grid point.
S7-26	3822301.96	311726.57	0.18	12.4	0.6	0 find magnetic signature 7 ft. E of grid point.
S7-27	3822277.99	311163.30	0.95	12.1	3.1	Empty 0 find
S7-28	3822121.58	311200.42	0.66	12.0	2.2	Empty 0 find magnetic signature 4ft. W of grid point.
S7-29	3822572.06	311923.05	0.76	11.9	2.5	0 find magnetic signature 3 ft.W of grid point.
S7-30	3822332.71	311472.09	1.09	11.5	3.6	Empty 0 find magnetic signature 6' E of grid point.
S7-31	3822206.18	311649.85	1.10	11.1	3.6	0 find magnetic signature 7' N of grid point.
S7-32	3822586.65	311307.98	0.84	11.1	2.8	0 find @ 3 ft. M-38 fragments located 5 ft. E of grid point @ a depth of 20".
S7-33	3822316.27	311779.04	1.01	10.7	3.3	M-38 fragments
S7-34	3822858.40	311399.70	0.40	10.7	1.3	Empty 0 find magnetic signature 4ft. W of grid point.
S7-35	3822189.11	311346.92	0.22	10.3	0.7	Magnetic soil- 0 find
S7-36	3822706.06	311610.41	0.80	10.0	2.6	0 find magnetic anomaly 6' E of hole.
S7-37	3822300.00	311110.52	0.51	10.0	1.7	M-38 fragments
S7-38	3822901.59	311328.71	1.21	9.9	4.0	Empty 0 find magnetic signature 4ft. S of grid point.
S7-39	3822799.01	311797.28	0.61	9.5	2.0	Empty 0 find
S7-40	3822403.45	311261.35	0.96	9.5	3.1	Empty 0 find magnetic signature 4 ft. S and E of grid point.
S7-41	3822161.60	311755.80	1.14	9.3	3.7	0 find magnetic signature 5 ft. E of grid point.
S7-42	3822744.56	311299.09	1.18	9.3	3.9	Empty signature 4 ft. W of grid point.
S7-43	3822304.73	311717.28	0.22	9.2	0.7	0 find
S7-44	3822709.14	311710.72	0.77	9.1	2.5	0 find @ grid point magnetic signature 3 ft. W of grid point- M-38 located @ 12"
S7-45	3822130.59	311278.74	1.30	9.1	4.3	Empty 0 find
S7-46	3822380.20	311394.88	1.03	9.0	3.4	Empty 0 find magnetic signature 6 ft. E of grid point.
S7-47	3822193.42	311388.64	0.88	8.9	2.9	0 find
S7-48	3822303.67	311174.83	1.40	8.8	4.6	M-38 fragments found @ 2' , dug to 4'
S7-49	3822168.83	311163.26	1.17	8.1	3.8	Empty 0 find magnetic signature 5 ft. S of grid point.
S7-50	3822110.69	311890.70	1.25	7.2	4.1	0 find magnetic singature 7 ft. S of grid point.

Appendix F
Matched Picks and Excavation Results from S-01 and S-02

S-01 statistical picks matched to excavation locations, 2m search radius.

Stat_id	Stat_x (m)	Stat_y (m)	Dig_id	Dig_x (m)	Dig_y (m)	Statmiss (m)	Description
5856	318673.00	3857246.00	1019	318674.57	3857246.04	1.57	"M-38 @ 45 degrees"
4480	318499.50	3857270.00	1023	318500.90	3857269.21	1.61	"M38 Bomb Body Fragments"
6691	318525.50	3857287.00	1024	318526.44	3857287.87	1.28	"MK-76 Practice Bomb"
9432	318618.50	3857265.50	1027	318620.35	3857266.08	1.94	"AN/M57 500# Bomb"
3737	318644.00	3857276.00	1029	318644.30	3857276.50	0.58	"M38 Bomb Body Fragments"
4938	318709.50	3857294.50	1031	318710.95	3857293.97	1.54	"M38 Bomb Body Fragments"
3908	318697.50	3857303.50	1032	318697.68	3857302.68	0.84	"M38 Bomb Body Fragments"
5079	318688.00	3857304.00	1033	318688.06	3857303.61	0.39	"M38 Bomb Body Fragments"
2708	318553.50	3857300.00	1036	318555.07	3857300.75	1.74	"MK-76 Practice Bomb"
3366	318521.00	3857316.00	1038	318522.66	3857317.02	1.95	"MK-76 Practice Bomb"
2231	318713.00	3857353.50	1050	318713.39	3857353.38	0.41	"M38 Bomb Body Fragments"
6369	318714.00	3857348.50	1052	318713.63	3857347.99	0.63	"MK-76 Practice Bomb"
5631	318757.00	3857384.00	1054	318758.43	3857382.62	1.99	"M38 Bomb Body Fragments"
1972	318726.00	3857366.50	1056	318727.54	3857365.52	1.83	"M38 Bomb Body Fragments"
2321	318726.50	3857376.50	1058	318726.79	3857376.38	0.31	"M38 Bomb Body Fragments"
2980	318722.50	3857385.50	1059	318724.17	3857384.66	1.87	"M38 Bomb Body Fragments"
3842	318658.00	3857374.50	1060	318657.98	3857374.78	0.28	"M38 Bomb Body Fragments"
4374	318669.00	3857372.50	1061	318668.41	3857373.34	1.03	"M38 Bomb Body Fragments"
3702	318643.00	3857381.00	1062	318642.81	3857380.65	0.40	"M38 Bomb Body Fragments"
5830	318551.00	3857378.50	1068	318551.48	3857377.86	0.80	"M38 Bomb Body Fragments"

8057	318580.50	3857412.50	1073	318581.06	3857411.78	0.91	"Bomb
4640	318615.00	3857390.50	1076	318616.35	3857391.08	1.47	"MK-76 Practice Bomb"
7928	318619.50	3857402.50	1077	318619.48	3857402.26	0.24	"M38 Bomb Body Fragments"
8442	318651.50	3857400.50	1078	318652.20	3857400.28	0.73	"M38 Bomb Body Fragments"
6076	318641.00	3857415.00	1080	318642.85	3857414.46	1.93	"M38 Bomb Body Fragments"
3265	318658.00	3857410.50	1081	318659.21	3857411.12	1.36	"M38 Bomb Body Fragments"
8197	318716.00	3857399.50	1083	318715.91	3857399.22	0.29	"M38 Bomb Body Fragments"
8435	318735.00	3857400.00	1085	318735.67	3857398.93	1.26	"M38 Bomb Body Fragments"
9459	318757.00	3857399.50	1086	318757.06	3857399.36	0.15	"M38 Bomb Body Fragments"
8319	318710.00	3857425.50	1090	318710.20	3857424.85	0.68	"Bomb
4823	318681.00	3857422.00	1093	318680.59	3857422.30	0.51	"M38 Bomb Body Fragments"
2726	318593.00	3857430.50	1095	318593.64	3857430.03	0.79	"MK-76 Practice Bomb"
4598	318522.50	3857426.50	1100	318522.52	3857427.05	0.55	"M38 Bomb Body Fragments"
4755	318514.00	3857417.50	1101	318515.70	3857417.83	1.73	"M38 Bomb Fin Assembly"
2305	318497.50	3857431.00	1104	318497.95	3857430.60	0.60	"M38 Bomb Body Fragments"
5136	318502.00	3857432.00	1105	318503.25	3857433.29	1.80	"M38 Bomb Body Fragments"
2022	318500.50	3857453.00	1106	318500.79	3857452.94	0.30	"M38 Bomb Body Fragments"
7618	318547.50	3857444.50	1107	318549.17	3857444.49	1.67	"AN/M57 500# Bomb"
6542	318540.50	3857465.50	1108	318542.12	3857465.48	1.62	"AN/M57 500# Bomb"
6093	318606.00	3857449.50	1112	318606.23	3857449.95	0.51	"Bomb
4606	318615.50	3857446.00	1113	318614.79	3857446.60	0.93	"M38 Bomb Body Fragments"
3050	318610.50	3857456.50	1114	318610.43	3857456.80	0.31	"M38 Bomb Body Fragments"
2098	318603.50	3857462.50	1115	318605.19	3857462.36	1.70	"M38 Bomb Body Fragments"
3085	318631.00	3857452.00	1116	318631.41	3857450.76	1.31	"M38 Bomb Body Fragments"
5988	318648.50	3857438.50	1118	318649.53	3857438.28	1.05	"M38 Bomb Body Fragments"

5383	318642.00	3857460.50	1119	318643.35	3857460.00	1.44	"M38 Bomb Body Fragments"
9127	318685.50	3857464.50	1122	318686.38	3857462.89	1.83	"Bomb
7597	318508.50	3857470.00	1126	318508.20	3857470.18	0.35	"M38 Bomb Body Fragments"
7947	318516.00	3857475.50	1128	318516.62	3857474.83	0.91	"M38 Bomb Body Fragments"
9253	318506.50	3857482.50	1129	318508.03	3857481.62	1.77	"M38 Bomb Body Fragments"
2644	318557.50	3857479.50	1130	318557.93	3857477.60	1.95	"Bomb
7891	318584.50	3857475.00	1131	318584.25	3857475.15	0.29	"M38 Bomb Body Fragments"
9276	318584.00	3857483.50	1132	318585.47	3857483.55	1.47	"M-38 Bomb Body Fragments"
7949	318592.00	3857478.50	1133	318592.71	3857477.87	0.95	"M38 Bomb Body Fragments"
3644	318595.00	3857475.50	1134	318595.06	3857474.25	1.25	"M38 Bomb Body Fragments"
6418	318611.00	3857478.50	1135	318611.56	3857478.81	0.64	"M38 Bomb Body Fragments"
5308	318620.00	3857480.00	1137	318620.01	3857479.69	0.31	"M38 Bomb Body Fragments"
5562	318629.00	3857484.00	1138	318630.62	3857483.14	1.83	"M38 Bomb Body Fragments"
2599	318639.50	3857491.00	1139	318641.03	3857490.72	1.56	"M38 Bomb Body Fragments"
4654	318641.00	3857473.00	1140	318641.10	3857472.63	0.38	"MK-76 Practice Bomb"
4328	318672.00	3857472.50	1141	318672.60	3857472.25	0.65	"MK-76 Practice Bomb"
6574	318738.00	3857485.50	1142	318739.55	3857484.87	1.67	"M38 Bomb Body Fragments"
5991	318747.50	3857480.00	1144	318748.41	3857478.90	1.43	"M38 Bomb Body Fragments"
2869	318757.00	3857478.00	1145	318757.13	3857477.50	0.52	"M38 Bomb Body Fragments"
6396	318762.50	3857472.50	1146	318762.68	3857471.82	0.70	"M38 Bomb Body Fragments"
4983	318521.00	3857511.00	1149	318522.03	3857510.16	1.33	"M38 Bomb Body Fragments"
3379	318526.50	3857505.50	1150	318527.17	3857505.91	0.79	"M38 Bomb Body Fragments"
5335	318558.50	3857501.50	1157	318559.02	3857501.51	0.52	"M38 Bomb Body Fragments"
7623	318561.00	3857505.00	1158	318562.43	3857506.04	1.77	"M38 Bomb Body Fragments"
7554	318582.00	3857504.50	1160	318582.41	3857505.82	1.38	"Bomb

2550	318657.50	3857506.00	1164	318658.02	3857506.98	1.11	"M38 Bomb Body Fragments"
4637	318685.50	3857494.50	1166	318685.64	3857494.65	0.21	"M38 Bomb Body Fragments"
8080	318733.50	3857492.00	1170	318733.25	3857490.98	1.05	"M38 Bomb Body Fragments"
6071	318737.50	3857506.50	1171	318738.23	3857506.34	0.75	"M38 Bomb Body Fragments"
9814	318760.50	3857515.50	1172	318760.85	3857515.59	0.36	"M38 Bomb Body Fragments"
1929	318750.50	3857529.00	1173	318752.24	3857528.32	1.87	"M38 Bomb Body Fragments"
8675	318757.00	3857540.00	1175	318756.04	3857539.80	0.98	"Bomb
6461	318690.00	3857528.50	1177	318691.79	3857528.26	1.81	"M38 Bomb Body Fragments"
2230	318674.00	3857519.00	1178	318674.72	3857519.72	1.02	"MK-76 Practice Bomb"
3598	318635.50	3857516.00	1180	318636.02	3857514.73	1.37	"M38 Bomb Body Fragments"
3754	318626.00	3857524.00	1181	318626.14	3857524.27	0.30	"M38 Bomb Body Fragments"
4427	318607.00	3857533.50	1182	318607.68	3857532.52	1.19	"M38 Bomb Body Fragments"
2999	318602.00	3857532.00	1183	318603.05	3857532.36	1.11	"M38 Bomb Body Fragments"
2771	318584.00	3857526.50	1184	318584.75	3857525.84	1.00	"MK-76 Practice Bomb"
6321	318579.00	3857533.00	1186	318580.06	3857532.63	1.12	"M38 Bomb Body Fragments"
6851	318574.50	3857533.50	1187	318575.28	3857533.17	0.85	"MK-76 Practice Bomb"
5610	318582.50	3857539.50	1188	318584.29	3857539.64	1.80	"MK-76 Practice Bomb"
2301	318565.50	3857530.50	1189	318566.78	3857529.66	1.53	"M38 Bomb Body Fragments"
5862	318558.50	3857523.50	1191	318558.90	3857523.39	0.41	"M38 Bomb Body Fragments"
3873	318556.00	3857520.50	1192	318556.36	3857520.31	0.41	"M38 Bomb Body Fragments"
5299	318565.00	3857517.00	1193	318564.73	3857516.78	0.35	"M38 Bomb Body Fragments"
1690	318549.50	3857522.00	1195	318549.70	3857521.26	0.77	"M38 Bomb Body Fragments"
4828	318522.00	3857525.50	1200	318522.07	3857525.35	0.17	"M38 Bomb Body Fragments"
3390	318517.00	3857522.00	1201	318517.54	3857521.46	0.76	"M38 Bomb Body Fragments"

4955	318500.50	3857515.00	1206	318502.02	3857513.97	1.84	"M38 Bomb Body Fragments"
7944	318502.00	3857549.00	1208	318502.95	3857547.82	1.51	"M38 Bomb Body Fragments"
8965	318508.50	3857550.50	1211	318508.45	3857549.65	0.85	"M38 Bomb Body Fragments"
2476	318514.00	3857540.00	1215	318514.95	3857541.01	1.39	"CLAMP
6072	318513.00	3857548.50	1216	318512.89	3857548.13	0.39	"M38 Bomb Body Fragments"
5231	318519.00	3857545.00	1217	318519.12	3857545.30	0.32	"M38 Bomb Body Fragments"
4808	318525.00	3857551.50	1219	318525.47	3857551.24	0.54	"M38 Bomb Body Fragments"
4000	318535.00	3857545.00	1223	318535.81	3857544.72	0.86	"M38 Bomb Body Fragments"
3199	318549.00	3857541.50	1226	318548.69	3857541.62	0.33	"M38 Bomb Body Fragments"
2737	318552.50	3857544.50	1227	318553.28	3857543.87	1.00	"M38 Bomb Body Fragments"
4517	318561.50	3857549.50	1228	318562.18	3857548.84	0.95	"M38 Bomb Body Fragments"
1506	318555.00	3857552.00	1229	318555.16	3857550.13	1.88	"M38 Bomb Body Fragments"
1900	318551.50	3857555.50	1230	318552.48	3857554.33	1.53	"M38 Bomb Body Fragments"
6685	318560.00	3857557.00	1231	318561.33	3857557.12	1.34	"M38 Bomb Body Fragments"
4396	318553.00	3857570.50	1235	318553.67	3857570.11	0.78	"M38 Bomb Body Fragments"
4474	318538.00	3857563.00	1237	318539.63	3857563.46	1.69	"M38 Bomb Body Fragments"
7753	318538.50	3857570.00	1238	318538.96	3857569.32	0.82	"M38 Bomb Body Fragments"
2711	318569.50	3857550.00	1239	318570.17	3857548.43	1.71	"M38 Bomb Body Fragments"
3812	318571.00	3857569.00	1240	318571.81	3857569.42	0.91	"M38 Bomb Body Fragments"
6463	318598.50	3857568.50	1245	318599.39	3857568.76	0.93	"M38 Bomb Body Fragments"
1783	318600.50	3857555.50	1246	318602.13	3857555.32	1.64	"M38 Bomb Body Fragments"
5795	318613.50	3857547.00	1247	318613.69	3857547.45	0.49	"M38 Bomb Body Fragments"
2002	318609.50	3857554.00	1248	318610.96	3857553.24	1.65	"MK-76 Practice Bomb"
2944	318603.00	3857558.00	1249	318604.62	3857557.43	1.72	"MK-76 Practice Bomb"

4222	318608.50	3857560.50	1250	318609.63	3857559.90	1.28	"M38 Bomb Body Fragments"
5292	318604.00	3857570.00	1251	318604.44	3857569.76	0.50	"M38 Bomb Body Fragments"
3513	318665.00	3857566.00	1256	318665.03	3857565.93	0.08	"M38 Bomb Body Fragments"
6758	318710.00	3857547.00	1261	318710.41	3857547.28	0.50	"M38 Bomb Body Fragments"
5635	318736.50	3857562.50	1266	318735.27	3857562.88	1.29	"M38 Bomb Body Fragments"
2879	318752.50	3857565.50	1268	318752.71	3857565.37	0.25	"M38 Bomb Body Fragments"
3938	318748.50	3857567.50	1269	318748.65	3857567.14	0.39	"M38 Bomb Body Fragments"
5223	318754.00	3857584.00	1271	318755.09	3857583.29	1.30	"M38 Bomb Body Fragments"
9841	318740.00	3857581.50	1272	318741.85	3857581.02	1.91	"AN/M57 500# Bomb"
6256	318739.50	3857567.50	1273	318739.99	3857567.46	0.49	"M38 Bomb Body Fragments"
9632	318723.00	3857569.50	1274	318723.88	3857567.78	1.93	"Unknown
5973	318616.50	3857575.00	1276	318616.91	3857574.66	0.53	"M38 Bomb Body Fragments"
5971	318597.50	3857573.50	1277	318598.15	3857573.77	0.70	"M38 Bomb Body Fragments"
3119	318593.50	3857577.50	1279	318593.93	3857576.39	1.19	"M38 Bomb Body Fragments"
704	318590.50	3857586.00	1280	318589.31	3857585.20	1.43	"M38 Bomb Body Fragments"
3392	318593.50	3857572.00	1305	318593.52	3857572.11	0.11	"M38 Bomb Body Fragments"
7889	318704.50	3857260.00	1307	318702.93	3857260.76	1.74	"AN/M57 500# Bomb"
2781	318702.50	3857325.50	1309	318702.94	3857325.18	0.54	"M38 Bomb Body Fragments"
5618	318714.00	3857325.00	1310	318714.42	3857324.57	0.60	"M38 Bomb Body Fragments"
8455	318730.00	3857335.50	1311	318730.93	3857335.18	0.98	"AN/M57 500# Bomb"
5900	318632.00	3857360.50	1313	318632.49	3857359.86	0.81	"M38 Bomb Body Fragments"
5513	318733.50	3857434.00	1316	318734.48	3857433.44	1.13	"M38 Bomb Body Fragments"
4751	318682.00	3857431.00	1317	318683.05	3857430.42	1.20	"M38 Bomb Body Fragments"
8448	318657.50	3857451.50	1318	318657.07	3857451.11	0.58	"M38 Bomb Body Fragments"

3716	318708.00	3857493.50	1323	318708.21	3857493.78	0.35	"M38 Bomb Body Fragments"
6142	318740.00	3857489.50	1324	318739.62	3857490.31	0.89	"M38 Bomb Body Fragments"
4792	318606.50	3857527.50	1326	318606.52	3857526.99	0.51	"M38 Bomb Body Fragments"
9682	318687.50	3857554.50	1328	318688.72	3857554.95	1.30	"M38 Bomb Body Fragments"
6034	318718.50	3857575.00	1330	318719.07	3857575.55	0.79	"M38 Bomb Body Fragments"
3338	318588.00	3857254.00	1334	318587.21	3857253.42	0.98	"M38 Bomb Body Fragments"
3549	318680.50	3857439.50	1339	318681.40	3857438.49	1.35	"M38 Bomb Body Fragments"
7360	318655.00	3857474.50	1340	318654.89	3857474.59	0.14	"M38 Bomb Body Fragments"
2540	318724.50	3857486.00	1341	318726.08	3857484.89	1.93	"M38 Bomb Body Fragments"
9023	318665.50	3857501.50	1342	318666.06	3857500.45	1.19	"M38 Bomb Body Fragments"
9373	318741.50	3857505.00	1343	318742.29	3857503.82	1.42	"MK-76 Practice Bomb"
5546	318734.00	3857518.50	1344	318734.97	3857517.84	1.17	"M38 Bomb Body Fragments"
7389	318589.00	3857536.00	1346	318590.75	3857535.73	1.77	"M38 Bomb Body Fragments"
5444	318736.00	3857571.00	1349	318736.77	3857571.41	0.87	"M38 Bomb Body Fragments"
9469	318676.50	3857284.50	1353	318677.16	3857284.53	0.66	"AN/M57 500# Bomb"
2591	318668.50	3857448.00	1357	318668.27	3857447.44	0.61	"M38 Bomb Body Fragments"
4169	318576.50	3857558.00	1362	318578.25	3857557.59	1.80	"M38 Bomb Body Fragments"
3215	318607.00	3857543.50	1364	318607.59	3857542.69	1.00	"M38 Bomb Body Fragments"
6545	318624.50	3857577.00	1368	318625.07	3857576.89	0.58	"M38 Bomb Body Fragments"
9912	318755.00	3858362.50	1382	318756.13	3858363.41	1.45	"Bomb
9692	318769.00	3858229.50	1387	318770.18	3858229.09	1.25	"Unknown
9814	318760.50	3857515.50	1389	318760.77	3857515.54	0.27	"Unknown

S-01 DAS picks matched to excavation locations, 2m search radius.

DAS_id	DAS_x (m)	DAS_y (m)	Dig_id	Dig_x (m)	Dig_y (m)	DASmiss (m)	Description
962	318525.53	3857287.55	1024	318526.44	3857287.87	0.96	"MK-76 Practice Bomb"
955	318571.45	3857270.46	1026	318573.25	3857270.26	1.81	"MK-76 Practice Bomb"
959	318618.52	3857266.88	1027	318620.35	3857266.08	2.00	"AN/M57 500# Bomb"
970	318630.36	3857277.74	1028	318630.90	3857277.06	0.87	"AN/M57 500# Bomb"
992	318687.98	3857304.63	1033	318688.06	3857303.61	1.02	"M38 Bomb Body Fragments"
968	318521.26	3857317.68	1038	318522.66	3857317.02	1.55	"MK-76 Practice Bomb"
971	318594.55	3857367.47	1046	318595.87	3857366.49	1.64	"MK-76 Practice Bomb"
969	318634.63	3857346.12	1048	318636.19	3857346.24	1.56	"MK-76 Practice Bomb"
993	318714.21	3857348.15	1052	318713.63	3857347.99	0.60	"MK-76 Practice Bomb"
988	318668.33	3857374.27	1061	318668.41	3857373.34	0.93	"M38 Bomb Body Fragments"
794	318580.27	3857412.28	1073	318581.06	3857411.78	0.93	"Bomb
786	318619.71	3857402.63	1077	318619.48	3857402.26	0.44	"M38 Bomb Body Fragments"
835	318651.71	3857400.66	1078	318652.20	3857400.28	0.62	"M38 Bomb Body Fragments"
845	318641.67	3857415.43	1080	318642.85	3857414.46	1.53	"M38 Bomb Body Fragments"
830	318735.34	3857400.13	1085	318735.67	3857398.93	1.24	"M38 Bomb Body Fragments"
836	318756.89	3857400.38	1086	318757.06	3857399.36	1.03	"M38 Bomb Body Fragments"
846	318709.82	3857425.54	1090	318710.20	3857424.85	0.79	"Bomb
790	318592.79	3857430.04	1095	318593.64	3857430.03	0.85	"MK-76 Practice Bomb"
801	318547.24	3857444.75	1107	318549.17	3857444.49	1.95	"AN/M57 500# Bomb"
800	318540.39	3857466.32	1108	318542.12	3857465.48	1.92	"AN/M57 500# Bomb"
806	318606.13	3857450.29	1112	318606.23	3857449.95	0.35	"Bomb
838	318642.23	3857460.87	1119	318643.35	3857460.00	1.42	"M38 Bomb Body Fragments"
829	318685.11	3857464.09	1122	318686.38	3857462.89	1.75	"Bomb
788	318508.06	3857470.68	1126	318508.20	3857470.18	0.52	"M38 Bomb Body Fragments"

821	318747.61	3857480.15	1144	318748.41	3857478.90	1.48	"M38 Bomb Body Fragments"
799	318560.96	3857505.73	1158	318562.43	3857506.04	1.50	"M38 Bomb Body Fragments"
802	318581.87	3857507.56	1160	318582.41	3857505.82	1.82	"Bomb
817	318733.06	3857492.11	1170	318733.25	3857490.98	1.15	"M38 Bomb Body Fragments"
828	318756.59	3857541.01	1175	318756.04	3857539.80	1.33	"Bomb
823	318690.15	3857528.49	1177	318691.79	3857528.26	1.66	"M38 Bomb Body Fragments"
784	318574.64	3857534.48	1187	318575.28	3857533.17	1.46	"MK-76 Practice Bomb"
783	318540.16	3857533.72	1196	318540.47	3857531.98	1.77	"M38 Bomb Body Fragments"
807	318502.48	3857548.97	1208	318502.95	3857547.82	1.24	"M38 Bomb Body Fragments"
803	318538.48	3857569.26	1238	318538.96	3857569.32	0.48	"M38 Bomb Body Fragments"
796	318598.57	3857568.16	1245	318599.39	3857568.76	1.02	"M38 Bomb Body Fragments"
797	318617.00	3857573.09	1276	318616.91	3857574.66	1.57	"M38 Bomb Body Fragments"
989	318702.24	3857260.90	1307	318702.93	3857260.76	0.70	"AN/M57 500# Bomb"
994	318713.81	3857324.28	1310	318714.42	3857324.57	0.68	"M38 Bomb Body Fragments"
995	318729.95	3857336.23	1311	318730.93	3857335.18	1.44	"AN/M57 500# Bomb"
812	318657.76	3857451.79	1318	318657.07	3857451.11	0.97	"M38 Bomb Body Fragments"
820	318718.60	3857576.20	1330	318719.07	3857575.55	0.80	"M38 Bomb Body Fragments"
972	318588.34	3857253.83	1334	318587.21	3857253.42	1.20	"M38 Bomb Body Fragments"
847	318655.08	3857475.17	1340	318654.89	3857474.59	0.61	"M38 Bomb Body Fragments"
824	318665.39	3857500.84	1342	318666.06	3857500.45	0.78	"M38 Bomb Body Fragments"
819	318741.45	3857504.99	1343	318742.29	3857503.82	1.44	"MK-76 Practice Bomb"

S-02 statistical picks matched to excavation locations, 2m search radius.

Stat_id	Stat_x (m)	Stat_y (m)	Dig_id	Dig_x (m)	Dig_y (m)	Statmiss (m)	Description
1434	325915.50	3839998.00	1	325915.74	3839997.92	0.25	"0 Find M-38 Body fragments (surface) 3 east of grid point"
1427	325758.00	3840505.00	2	325758.08	3840505.23	0.24	"0 Find M-38 Body fragments (surface) about 8 ft. east of grid"
1426	326241.50	3840212.50	3	326242.22	3840213.22	1.02	"0 Find @ grid M-38 fragment 3 ft. NE of grid point"
1397	325896.00	3840406.00	4	325895.97	3840406.73	0.73	"M-38 Bomb body fragment 1 ft. N of grid point-surface"
473	325986.50	3840475.50	5	325986.44	3840475.45	0.08	"0 Find"
1348	326346.50	3840256.50	6	326346.68	3840256.13	0.41	"M-38 Fragment 1 ft. N of grid point"
1003	325925.50	3840611.50	7	325925.40	3840611.29	0.23	"0 Find"
199	325797.50	3840515.00	8	325797.58	3840515.08	0.11	"0 Find"
1335	326022.50	3840382.50	9	326022.17	3840382.79	0.44	"0 Find Surface fragment 4 ft. from grid point south"
677	326338.50	3840400.50	10	326338.41	3840400.64	0.17	"M-38 fragment on surface 3 ft. N of grid point"
1001	326279.00	3840226.00	11	326279.03	3840225.98	0.04	"M- 38 Fragment M-38 bomb body fragment on surface of grid point"
974	326291.00	3840376.50	12	326290.94	3840376.42	0.10	"0 Find M-38 Fragments 3 ft. E & W of grid point"
1208	326247.50	3840139.50	13	326247.52	3840139.52	0.03	"M-38 Fragment 1 ft. S of grid point"
338	325742.00	3840283.00	14	325741.87	3840282.86	0.19	"0 Find magnetic signature 8 ft. S of grid point"
663	325735.50	3840199.50	15	325735.81	3840199.82	0.45	"0 Find"
1171	326239.00	3840037.00	16	326239.46	3840037.33	0.57	"M-38 Fragments M-38 fragments

							@ 6"
1157	326207.50	3840008.00	17	326207.37	3840007.87	0.18	"0 Find M-38 bomb body on surface 3 ft. E of grid point"
201	326163.00	3840024.00	18	326163.14	3840024.14	0.20	"Magnetic rock Grid point surrounded by voleanic rock-magnetic"
207	326357.50	3840151.50	19	326357.54	3840151.57	0.08	"0 Find M-38 fragmentson surface8 ft. E of grid point"
1029	326376.00	3840305.00	20	326375.92	3840305.08	0.11	"0 Find M-38 Fragment on surface 4 ft. E of grid point"
606	326372.00	3840247.50	21	326372.00	3840247.64	0.14	"M-38 Fragment 1 ft. N of grid point"
1152	325867.50	3840607.50	22	325867.42	3840607.74	0.25	"0 Find magnetic signature 4 ft. E of grid point"
1302	325776.50	3840381.50	23	325776.45	3840381.52	0.05	"0 Find M-38 fragment on surface 3' E of grid point"
831	326111.00	3840183.50	24	326111.06	3840183.46	0.07	"M-38 fragments surface around grid point cluttered w/ M-38 fragments"
429	326273.00	3840090.50	25	326272.90	3840090.53	0.10	"0 Find M-38 Bomb body fragments on surface 5 ft. S of grid point"
569	326390.00	3840052.00	26	326389.94	3840052.03	0.07	"0 Find"
1031	325841.00	3840417.50	27	325841.00	3840417.35	0.15	"0 Find magnetic signature 4 ft. N of grid point"
827	325799.50	3840495.50	28	325799.59	3840495.27	0.25	"0 Find M-38 Bomb fragments on surface 8 ft. E of grid point"
305	326045.50	3840254.00	29	326045.95	3840253.79	0.50	"M-38 fragments 6" S of grid point

							M-38 fragments scattered all around grid point"
989	326063.00	3840088.00	30	326062.89	3840088.05	0.12	"0 Find"
1154	326337.50	3840377.00	31	326337.50	3840377.05	0.05	"0 Find M-38 fragment on surface 2 ft. E of grid point"
1051	326183.00	3839927.50	32	326183.13	3839927.70	0.24	"0 Find M-38 fragment on surface 8 ft.E of grid point"
471	325972.50	3840358.50	33	325972.41	3840358.79	0.30	"0 Find"
920	326075.00	3839987.00	35	326074.91	3839986.81	0.21	"0 Find M-38 fragment on surface 6 ft. E of grid"
946	326120.00	3840179.50	36	326119.97	3840179.56	0.07	"0 Find surface area around grid point cluttered w/ M-38 fragments"
1145	325771.00	3840426.00	37	325771.15	3840425.85	0.21	"0 Find surface fragment 6 ft. E from grid point"
1042	326153.50	3840068.50	38	326153.54	3840068.95	0.45	"M-38 fragment located in N end of hole M-38 fragment on surface 5' E of grid point"
874	326292.00	3840390.00	39	326292.20	3840390.20	0.28	"M-38 Fragments"
688	326247.00	3840250.50	40	326247.14	3840250.63	0.19	"0 Find M-38 fragment on surface 3' NE of grid point"
1129	326383.50	3840018.50	41	326383.54	3840018.49	0.04	"0 Find M-38 fragment on surface 3' S of grid point"
424	325738.00	3840051.50	42	325738.32	3840051.36	0.35	"M-38 Fragment M-38 fragment on surface 6' S of grid point"
549	326334.00	3840361.50	43	326333.91	3840361.52	0.09	"0 Find M-38 Fragment on surface 4 ft. E of grid point"

1050	326082.00	3839938.00	44	326082.06	3839938.00	0.06	"0 Find M-38 fragment 6' NE of grid point"
837	326233.00	3840017.00	45	326232.93	3840016.96	0.08	"0 Find M-38 fragments on surface 5' E of grid point"
810	326142.50	3840152.00	46	326142.64	3840152.02	0.14	"0 Find surface area around grid point cluttered w/ M-38 fragments"
872	326190.50	3839933.50	47	326190.58	3839933.64	0.16	"0 Find"
1101	325857.00	3840513.50	48	325857.11	3840513.41	0.14	"0 Find"
446	326227.50	3840054.00	49	326227.48	3840053.77	0.23	"0 Find M-38 fragment on surface 4 ft. N of grid point"
488	325889.00	3840496.00	50	325889.04	3840495.72	0.28	"0 Find"

S-02 DAS picks matched to excavation locations, 2m search radius.

Das_id	DAS_x (m)	DAS_y (m)	Dig_id	Dig_x (m)	Dig_y (m)	Dasmis (m)	Description
192	325916.14	3839998.23	1	325915.74	3839997.92	0.51	"0 Find M-38 Body fragments (surface) 3 east of grid point"
9	325758.83	3840505.66	2	325758.08	3840505.23	0.86	"0 Find M-38 Body fragments (surface) about 8 ft. east of grid"
293	326242.89	3840212.77	3	326242.22	3840213.22	0.81	"0 Find @ grid M-38 fragment 3 ft. NE of grid point"
164	325894.76	3840406.83	4	325895.97	3840406.73	1.21	"M-38 Bomb body fragment 1 ft. N of grid point- surface"
219	325985.63	3840474.93	5	325986.44	3840475.45	0.96	"0 Find"
345	326346.70	3840256.60	6	326346.68	3840256.13	0.47	"M-38 Fragment 1 ft. N of grid point"
153	325926.99	3840612.19	7	325925.40	3840611.29	1.83	"0 Find"
220	326022.89	3840382.92	9	326022.17	3840382.79	0.73	"0 Find Surface fragment 4 ft. from grid point south"
320	326337.63	3840400.88	10	326338.41	3840400.64	0.82	"M-38 fragment on surface 3 ft. N of grid point"
346	326278.07	3840226.37	11	326279.03	3840225.98	1.04	"M- 38 Fragment M-38 bomb body fragment on surface of grid point"
295	326247.43	3840140.18	13	326247.52	3840139.52	0.67	"M-38 Fragment 1 ft. S of grid point"
13	325743.00	3840282.81	14	325741.87	3840282.86	1.13	"0 Find magnetic signature 8 ft. S of grid point"
15	325735.63	3840198.70	15	325735.81	3840199.82	1.13	"0 Find"
306	326207.57	3840008.76	17	326207.37	3840007.87	0.91	"0 Find M-38 bomb body on surface 3 ft. E of grid point"

362	326376.53	3840305.55	20	326375.92	3840305.08	0.77	"0 Find M-38 Fragment on surface 4 ft. E of grid point"
365	326371.20	3840248.20	21	326372.00	3840247.64	0.98	"M-38 Fragment 1 ft. N of grid point"
81	325776.93	3840381.95	23	325776.45	3840381.52	0.64	"0 Find M-38 fragment on surface 3' E of grid point"
375	326390.76	3840052.30	26	326389.94	3840052.03	0.86	"0 Find"
78	325840.36	3840418.23	27	325841.00	3840417.35	1.09	"0 Find magnetic signature 4 ft. N of grid point"
67	325800.70	3840496.13	28	325799.59	3840495.27	1.40	"0 Find M-38 Bomb fragments on surface 8 ft. E of grid point"
237	326063.82	3840088.28	30	326062.89	3840088.05	0.96	"0 Find"
314	326183.72	3839927.91	32	326183.13	3839927.70	0.63	"0 Find M-38 fragment on surface 8 ft.E of grid point"
225	325970.93	3840359.41	33	325972.41	3840358.79	1.60	"0 Find"
76	325771.21	3840426.01	37	325771.15	3840425.85	0.17	"0 Find surface fragment 6 ft. E from grid point"
34	325736.37	3840051.17	42	325738.32	3840051.36	1.96	"M-38 Fragment M-38 fragment on surface 6' S of grid point"
281	326082.09	3839938.25	44	326082.06	3839938.00	0.25	"0 Find M-38 fragment 6' NE of grid point"
273	326141.71	3840152.32	46	326142.64	3840152.02	0.98	"0 Find surface area around grid point cluttered w/ M-38 fragments"
312	326190.39	3839933.64	47	326190.58	3839933.64	0.19	"0 Find"
71	325855.58	3840513.31	48	325857.11	3840513.41	1.53	"0 Find"